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PERFORMANCE MEASUREMENT OF NONVERBAL MEDIATION: A DIGITAL READOUT VERSION OF THE CODE TRANSFORMATION TASK (DR-COTRAN)

by Earl A. Alluisi, Ben B. Morgan, Jr., and Thomas K. Dempsey

Prepared by

UNIVERSITY OF LOUISVILLE

Louisville, Ky.

for

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Abstract

The results of four experimental investigations of the performance obtained with a digital-readout (DR) version of the code-transformation (COTRAN) task are reported. A three-phase (3P) version of the COTRAN task was developed previously (cf. Alluisi & Coates, 1967) to provide a means for obtaining performance measurements of that part of intellectual functioning which is typically called "nonverbal mediation;" both versions of the task are modeled after the problem-solving paradigm.

The first two experiments were preliminary or background investigations that sought to compare (a) the factorial structures of the DR-COTRAN and 3P-COTRAN tasks, and (b) the relative sensitivities of the two versions to practice effects and to the effects of infectious disease (subjects ill with Sandfly fever), when both tasks were used alone without any requirement for time-sharing. The third study was intended to measure the acquisition of skill on the DR-COTRAN task and the influence of practice on the nonverbal mediation measured with the task. The fourth, and final, investigation measured the effects of operator loading on DR-COTRAN performances, and, conversely, the effects of adding the DR-COTRAN task to various combinations of tasks currently employed in a multiple-task performance (MTP) battery (cf. Alluisi, 1969; Alluisi & Chiles, 1967; Chiles *et al.*, 1968).

Each of the four experiments is presented and discussed separately, and the report is concluded with a relatively brief general discussion in which the results are compared with those of similar studies previously made of the 3P-COTRAN task (Alluisi & Morgan, 1968). The general conclusion reached was as follows: The DR-COTRAN task permits the measurement of the same nonverbal-mediational aspects of intellectual functioning as provided for in the third, or problem-solving, phase of the 3P-COTRAN task. The two versions of the COTRAN task differ in terms of some apparently nonessential characteristics, and in these cases the differences favor the DR-COTRAN version for use as an additional task in the MTP battery.

Foreword

This report was prepared by Dr. Earl A. Alluisi, Professor of Psychology, Research Professor and Director, Dr. Ben B. Morgan, Jr., Assistant Research Professor, and Mr. Thomas K. Dempsey, Graduate Research Assistant, all of the Performance Research Laboratory, University of Louisville, Louisville, Kentucky 40208. The research program under which this work was completed was supported by the National Aeronautics and Space Administration under Research Grant No. SC/NGR-18-002-008, "Performance Measurement of Nonverbal Mediation," monitored by the Human Performance Branch, Biotechnology Division, Life Sciences, NASA Ames Research Center, Moffett Field, California.

Part of the research reported is based on a master's thesis prepared by the junior author under the direction of the senior author and the immediate supervision of the secondmost senior author. The second experiment reported was conducted at the U. S. Army Medical Research Institute of Infectious Diseases, Fort Detrick, Frederick, Maryland 21701, in conjunction with two studies of the behavioral effects of Sandfly fever on man, supported in part by the U. S. Army Medical Research and Development Command, Office of the Surgeon General, Department of the Army, under Contract No. DA-49-193-MD-2567, "Behavioral Effects of Infectious Diseases." The authors wish to express their appreciation to all members of the laboratory staff for their interest, guidance, and helpful suggestions during the course of the research, and especially to Mr. Karl E. Rothrock for his assistance in the design, construction, and maintenance of the apparatus.

Distribution of this report is provided in the interest of information exchange. Responsibility for the contents resides in the authors or organization that prepared it.

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Introduction

The assessment of human performance in operational systems is an important and continuing requirement of human factors engineering. Yet, past evaluations of the performances of man-machine systems have tended to be focused principally on the machine components, rather than the human, and researchers have been concerned more generally with the output of the system than with the performance of the man within the system (cf. Bray, 1948; Chapanis, 1961; Fitts, 1962; McCormick, 1964; Sinaiko & Buckley, 1961).

Partly in order to correct this situation by the development of suitable methodologies, numerous "performance batteries" or combinations of tests of human performance have been designed (see the recent excellent review of Finley et al., 1969). A multiple-task performance (MTP) battery is one of those that has been employed with some success; it is based on a synthetic-work approach to performance assessment.

Synthetic Work and the MTP Battery

The synthetic-work approach (Alluisi, 1967, 1969; Chiles et al., 1968) has been developed to provide measurements and evaluations (assessments) of human performance in a work-behavior domain synthesized within a man-machine system setting. The man's job or work situation is created by a synthesis of several time-shared tasks that represent functions which man is called upon to perform in many different jobs. It is a compromise between the use of full-scale simulation on the one hand, and specific-test techniques on the other.

Specifically, the synthetic-work approach provides less face validity, but greater generality than full-scale, integrated, mission simulation (cf. Grodsky, 1967; Grodsky et al., 1966); it provides more face validity at the price of less well established content validity than the best of the factor-analytically based specific-test techniques (cf. Fleishman, 1967; Parker, 1967). Basically, it provides a job situation in which men work, at realistically high levels of skill and with realistically varying levels of workload. The front view of an operator panel from one of the MTP batteries used in the synthetic-work approach to the study of performance assessment is shown in Figure 1.

Figure 1.--Photograph of the front view of an MTP operator panel.

Behavioral measures are obtained from the operator's performance in working at the six tasks presented with the panel. The tasks are generally displayed at each of five identical work stations--one for each member of a 5-man crew. Three watchkeeping tasks are used to measure the performance of watchkeeping, vigilance, and attentive functions (warning-lights, blinking-lights, and probability monitoring). Three active tasks are used to measure the performance of memory functions (arithmetic computations), sensory-perceptual functions (target identifications), and procedural functions (code-lock solving). Communication functions are not measured directly, although they are involved to some extent in the performance of all three active tasks.

Detailed descriptions of the MTP battery have been published elsewhere (cf. Alluisi, 1969; Chiles et al., 1968). All of the tasks currently used show very high reliabilities (Alluisi & Chiles, 1967; Alluisi et al., 1962; Chiles et al., 1968; Passey et al., 1964), and have done so since their earliest use (Adams et al., 1959). For further details, the papers cited should be consulted, especially the three summary papers (Alluisi, 1969; Alluisi & Chiles, 1967; Chiles et al., 1968).

Some attempts have been made to employ tracking tasks with MTP batteries (e.g., Adams et al., 1959; Chambers et al., 1966), and tasks have been designed to measure directly either a kind of decision-making behavior (cf. Rebbin, 1969) or certain nonverbal-mediational aspects of intellectual functioning (cf. Alluisi & Coates, 1967, 1969; Alluisi & Morgan, 1968). It is with this last performance function that the present paper deals. That is to say, the investigations reported here are part of a continuing program of research aimed at the further development of a task that can be used alone or as part of an MTP battery to provide direct performance measures of the nonverbal-mediational aspects of man's intellectual functioning.

Measurement of Nonverbal Mediation: 3P-COTRAN

Although the majority of the problem-solving tasks employed prior to 1953 were of the parlor-game variety (29 tasks of this type have been described by Ray, 1955), attempts have been made subsequently to develop tasks that would permit precise experimental investigations of man's problem-solving behavior. One such task has been developed under the current research program (see Alluisi & Coates, 1967, 1969; Alluisi & Morgan, 1968); namely, the three-phase code transformation task (3P-COTRAN) that is shown in Figure 2. Based on a modification of the "code-lock solving" task of the MTP battery, this initial version of the COTRAN task consists of three working elements: a response board, an information panel, and a memory unit.

Figure 2.--Photograph of the 3P-COTRAN apparatus showing the operator's memory unit, information panel, and response board.

The response board consists of five response keys arranged to fit the fingers of the operator's right hand. The information panel consists of three primary indicator lights on a sloping panel (amber, red, and green, from left to right), and three secondary indicator lights (all blue) on the lower front of the display. The blue lights are used to indicate the current phase of the problem (I to III, from left to right), whereas the red, amber, and green lights provide the information necessary for the problem's solution. The memory unit consists of two memory aids, each with a bank of five, 5-position rotary switches which can be set to point to one of five numbers (1 through 5). Use of the two memory aids permits the operator to record his phase-I and phase-II solutions.

The three phases of the task are performed sequentially. In phase I, the operator is required to discover, by means of a systematic trial-and-error search procedure, the proper sequential order for depressing the five response keys (one for each finger of the right hand). The three primary indicator lights on the sloping panel are used by the operator, as described below, in discovering the correct sequence.

The amber light is illuminated when the operator depresses any of his response keys, and it is extinguished when the key is released. The red light, which was illuminated as the signal for the start of the problem, remains illuminated unless the key that was pressed is the correct first response. If it is the correct first response, then the red light is extinguished at the same time as the amber light, and it will remain extinguished until an incorrect or out-of-sequence response is made. When this occurs, the red light is re-illuminated, and the programming apparatus is reset automatically to the beginning of the sequence. Then, in order to recommence the search for a solution, the correct first response key has to be depressed first, the correct second response key has to be depressed next, etc. When all five response keys have been depressed in the correct order, the green light is illuminated as a signal that the sequence presented in phase I has been completed, and the operator can now record his solution on the memory unit.

Following a between-phase pause of 30 sec., the green light will go off, the red light will come on, and the operator is presented with phase II of the problem. Phase II is identical to phase I except that it involves a different sequence. The left-most blue light is lit during phase I, and the second or middle light is lit during phase II.

When the red light comes on at the beginning of phases I and II, the operator has no way of knowing or predicting the correct sequence. Rather than have him search for the sequence in a haphazard manner, he is instructed to work systematically. Specifically, he is instructed to initiate his search for each part of the sequence with the left-most available key and to search in the direction of the right-most available key. This procedure distributes the keypressing workload in direct relation to the dexterity of the fingers (most to the thumb, index, and middle fingers, and least to the ring and little fingers; cf. Dvorak et al., 1936).

During phase III, which begins immediately upon completion of the phase-II sequence, the right-most blue light is lit and the operator must begin to deduce from the sequences (solutions) of phases I and II the transformation that must have been applied to the phase-I sequence in order for it to have generated the phase-II sequence. That is to say, the operator must determine how the phase-I sequence (which he has entered on the top memory aid) would have had to change in order for it to have become the phase-II sequence (which he has entered on the bottom memory aid). He is then required to apply the deduced transformation to the phase-II sequence in order to solve the third phase of the problem. The problem is solved when the correct five keypressing responses of the phase-III sequence have been made.

Prior experimentation with the 3P-COTRAN task has indicated that it can be used in the measurement of that aspect of intellectual functioning or problem-solving behavior which is generally identified as nonverbal mediation (Alluisi & Coates, 1967, 1969). It has also been used successfully as a vehicle for the study of skilled problem-solving performance (Alluisi & Morgan, 1968). Furthermore, it seems to have satisfied most if not all of the criteria against which it was developed; namely, (1) that it should provide a large number of problems of comparable difficulty and solvable according to a single principle, (2) that solution of the problems should require a minimum of technical or specialized knowledge, (3) that solution of one problem should facilitate subsequent solutions (i.e., practice should improve performance, at least for a finite number of problems solved), (4) that the task should provide for several measures of nonverbal mediation as well as for replication of each measurement during reasonably short intervals of time, and (5) that it should provide for experimental controls of the important variables associated with nonverbal mediation.

However, certain practical limitations to the use of the 3P-COTRAN task also have been noted. Four important limitations have been identified as follows:

(1) Relatively extensive instructions are required to train operators to perform this task. The instructions are quite detailed and require 30 minutes or more for presentation, thereby reducing the time available for performing 3P-COTRAN problems during the initial experimental session (typically of 50-minutes duration).

(2) The rate at which problems are solved is relatively slow; the presentation and solution of a problem on the average requires from 1 1/2 to 2 minutes. This means that no more than 30 to 40 problems can be presented per 1-hour session subsequent to the initial or instruction session. Since asymptotic performance is not reached until after the solution of between 108 and 162 problems (see Alluisi & Morgan, 1968), from 4 to 6 hours of practice are required before skilled performance can be investigated (and, if the practice had to be time-shared with other tasks, e.g. on the kind of schedule used with the MTP battery, it is estimated that between 24 and 30 hours of such performance might be required before asymptotic performance of the 3P-COTRAN task would be reached).

(3) The limitation stated in 2, above, also means that the 3P-COTRAN task could not be used reliably with brief 10 to 15-minute performance periods since only 5 to 10 problems would be solved on the average within such intervals of time. Past experience with the MTP battery has indicated that reliable measurements can be made with 30 to 45 problems (e.g., the target-identification and arithmetic-computation tasks, respectively). As indicated earlier, this many problems would require a minimum of 1 hour with the 3P-COTRAN task, whereas the task-performance schedule used with the MTP battery is most compatible with task-performance intervals of 15-minutes duration.

(4) Experimental control of problem difficulty, as reflected in the variable of transformation complexity (the number of elements in a sequence whose positions are changed in order to produce the sequence for the next phase: see Alluisi & Coates, 1967, p. 8, for a discussion of this variable), is only partly attained with the 3P-COTRAN task prior to asymptotic performance (Alluisi & Morgan, 1968).

Because of these limitations, it seemed desirable to design a second version of the basic COTRAN task--a version which, hopefully, would be less subject to such shortcomings, but which nevertheless would provide equally valid and useful measures of nonverbal mediation.

Measurement of Nonverbal Mediation: DR-COTRAN

A digital-readout code transformation task (DR-COTRAN) has been developed as a modification that eliminates the systematic search procedures of phases I and II of the 3P-COTRAN task. Instead, the information that would have been gained from these phases (and entered by the operator on the two banks of rotary switches provided with the memory unit) is presented to the operator in the DR-COTRAN task by use of two banks of digital displays. Phase III, the problem-solving phase of the 3P-COTRAN task is left intact as the only "phase" of the DR-COTRAN task. The digital-display version of the COTRAN task consists of three working elements as shown in Figure 3: a response board, an information panel, and a digital-display unit.

The response board and information panel are identical to those used in the three-phase version of the task, but the digital-display unit replaces in the DR-COTRAN task the memory unit employed with the 3P-COTRAN task. The digital-readout unit consists of two rows of five digital-readout numerical indicators, each of which can be made to display one of five numerals (1 through 5).

In performing the DR-COTRAN task, the operator is required essentially to do the same things required of him during the phase-III portion of the 3P-COTRAN task. Specifically, he must solve a set of problems, each of which consists of determining the proper sequential order for depressing the five response keys on the basis of the numerical information presented on the digital-display unit.

Figure 3.--Photograph of the DR-COTRAN apparatus showing the operator's digital-display unit, information panel, and response board.

The five integers presented on each bank of the digital-display unit represent a sequence or order comparable to the phase-I and phase-II solutions in the earlier version of the task (3P-COTRAN). Problem solutions are attained by comparing the first with the second sequence (i.e., the upper with the lower bank of the digital-display unit) in order to determine what changes (transformations) were made in the first sequence to produce the second. The transformation thus determined must then be applied to the second sequence in order to produce a new sequence which is pressed out on the keys of the response board.

The three indicator lights (red, amber, and green) on the sloping surface of the information panel provide additional information, especially with regard to the correctness of the responses. The red light is illuminated at the beginning of each problem to signal the problem onset. This light is also illuminated whenever an incorrect response is made. The amber light is lit whenever any response key is depressed and remains illuminated until the response key is released. The green light is illuminated only after the entire sequence of five keypresses has been pressed in the correct order. The illumination of this light indicates successful solution and completion of a problem.

On the surface, the DR-COTRAN task seems to have certain advantages over the 3P-COTRAN task as follows: (1) Operators can be given complete instructions on the task in less than 5 minutes (as compared with 30 minutes for the three-phase version). (2) The DR-COTRAN problems can be solved at the rate of one every 45 to 55 seconds, on the average, so that up to 80 problems could be presented within an hour, and as many as 20 during a 15-minute period.

These advantages are sufficient to dictate the selection of the DR-COTRAN task over the 3P-COTRAN task for use with the MTP battery, provided it can be shown that both provide essentially identical performance measures of nonverbal mediation.

Plan of Studies

The results of four investigations of the performance obtained with the DR-COTRAN task are presented in the remaining sections of this report. The first two were preliminary or background investigations thvt sought to compare (1) the factorial structures of the digital-readout and three-phase versions of the COTRAN task, and (2) the relative sensitivities of the two versions to practice effects and to the effects of infectious disease (subjects ill with Sandfly fever). The third study was intended to measure the acquisition of skill on the DR-COTRAN task and the influence of practice on the nonverbal mediation measured with the task. The fourth, and final, investigation measured the effects of operator loading on DR-COTRAN performance. Each of the four experiments is presented and discussed separately, and the report is concluded with a relatively brief general discussion that includes a summary of the conclusions reached.

Experiment I

The purpose of the first experiment was to obtain data on the basis of which a comparison could be made of the factor structures of the DR- and the 3P-COTRAN tasks.

Method

Two groups, each consisting of 20 subjects, were tested individually. Each subject in group I-DR completed 27 DR-COTRAN problems, and each subject in group I-3P completed a similar number of 3P-COTRAN problems. The data of the two groups were then factor analyzed and compared.

Apparatus.--The apparatus consisted of the three basic components of either the 3P-COTRAN task (response, information, and memory units) or the DR-COTRAN task (response, information, and digital-display units) used by the subject and two components used by the experimenter for programming and scoring. The positioning of the response keys was determined from 10 male and 10 female subjects on the basis of measurements

of the natural positioning of the fingers of the right hand when at rest; the exact dimensions are given elsewhere (Coates, 1966, Fig. 2).

The six, 1/2-in. diameter jeweled indicator lights on the subject's information panel were mounted as previously shown in Figures 2 and 3. The blue lights were used to indicate the phase of the 3P-COTRAN problem on which the subject was working (I to III, from left to right), whereas the red, amber, and green lights provided the information necessary for the solution of phases I and II, as well as feedback with regard to phase III and the single phase of the DR-COTRAN problems. The subject's response and information units were mounted on a 30-by-20 in. response board which in turn was mounted on a 30-by-30 in. table. The top of the table was 27 in. above the floor. The memory (3P-COTRAN) and digital-display (DR-COTRAN) units were as previously described (cf. Figures 2 and 3).

The experimenter's programming unit consisted of three banks of five, 5-position rotary switches--one bank for each of the three phases of a problem in the 3P-COTRAN task, or for the two digital-readout displays and single performance "phase" of a problem in the DR-COTRAN task. The experimenter programmed the correct sequences on these banks of rotary switches, which were connected electrically to a stepping switch and a series of relays that served to score the correctness of the subject's responses. Thus, in conjunction with the programming unit, the scoring unit permitted the experimenter to monitor accurately the subject's performance of either task. The subject's total responses, errors, and response times (to the nearest 0.1 sec.) were recorded on electromechanical counters.

Subjects.--The subjects were 40 undergraduate male students at the University of Louisville. They were volunteers from the Naval and Air Force ROTC units who were paid for their participation in the study. The subjects ranged in age from 18 to 25, with a median of 19 years. All 20 subjects in group I-3P completed their testing with the 3P-COTRAN task prior to the testing of the 20 subjects in group I-DR who performed the DR-COTRAN task.

Procedure.--Each subject served in one experimental session during which he solved nine blocks of three problems, or a total of 27 problems in all. Each block of problems consisted of a three-, four-, and five-element transformation; the order of presentation of the three transformation complexities was counterbalanced throughout the session.

The subject and his apparatus occupied a 7-by-14 ft. experimental room in which an overhead florescent light fixture provided ambient illumination. The experimenter's apparatus was placed in an adjoining room and was connected to the subject's by a single cable. Approximately 70 dB of board-band noise were used in the experimental room to mask the sound of the programming unit and to isolate the subject from other extraneous sounds.

During the session, each subject received a standard set of instructions for either the 3P- or the DR-COTRAN task, then solved 27 problems.

The session was usually about 2-hr. duration for the subjects in group I-3P, and 1-hr. duration for those in group I-DR. Subjects were instructed to solve the COTRAN problems as quickly as possible, but to keep errors at a minimum. Each problem (and phases I and II of each 3P-COTRAN problem) was separated from the subsequent problem by a 30-sec. "green light" interval or "no response" delay. The data recorded were the response times, errors, and total responses for each DR-COTRAN problem and for the phase-III portion of each 3P-COTRAN problem.

Results and Discussion

Ten additional measures were computed from the recorded basic data, so that a total of 13 measures was used as shown in Table 1. These measures were intercorrelated and factor analyzed (separately for the two versions of the task) by use of the principle-axis method with the highest off-diagonal correlation as the estimate of communality. Three factors were extracted from each set of data, and these factors were then rotated according to the Varimax criterion.

Initial comparisons of the factor structures suggested that the Varimax rotations produced differential structures for the two versions of the task. The factors were further rotated (by hand) to correspond visually as closely as possible; the resultant factor loadings are shown in Table 2. The coefficients of correlations between the corresponding factors obtained with the two versions of the COTRAN task were +.790, +.872, and +.928 for Factors I, II, and III, respectively ($P < .01$, $df = 11$ in each case). It can be concluded that the factor structures of the two versions are essentially identical, so the identification of the factors apply equally well to either set of data.

Factor I is characterized by the high negative loadings of six measures (numbers 1, 2, 3, 4, 6, and 13) and the high positive loading of one measure (number 9). It is obviously a general problem-solving (or 3P-COTRAN phase-III) factor. Long response times (measure number 1), high errors (number 2), and large numbers of responses (number 3) produce low scores on this factor, as do also large numbers of errors per unit response time (measure number 4), or per unit response event (number 6), or high equivocation rates while responding (number 13), or high numbers of total responses per problem (number 9). For subsequent analyses, measures number 1, 2, and 3 will be taken to represent this factor most clearly.

Factor II is characterized by the high negative loadings of two measures (numbers 1 and 11) and the high positive loadings of two other measures (numbers 5 and 7); all four are time-based or time-related measures. This factor is identified as speed in problem solving; it corresponds essentially to factor IV (time in problem solving) as identified in previous studies of the 3P-COTRAN task (Alluisi & Coates, 1967, p. 19; Alluisi & Morgan, 1968, p. 17). A high number of responses per unit response time (measure number 5), or a low total response time per unit problem (number 7) would produce high scores on this factor, and these measures (numbers 5 and 7) will be taken in subsequent analyses to represent factor II.

Table 1

Identification and Definition of the Thirteen Measures of COTRAN Performance Employed

Measure Number	Measure Identification	Algebraic Definition*
1.	Total response time.	(TT)[a]
2.	Total errors	(E)[b]
3.	Total responses.	(TR)
4.	Ratio of total errors to total response time	(E/TT)
5.	Ratio of total responses to total response time. . .	(TR/TT)
6.	Ratio of total errors to total responses	(E/TR)
7.	Reciprocal of total response time.	(1/TT)
8.	Reciprocal of total errors	(1/E)
9.	Reciprocal of total responses.	(1/TR)
10.	Ratio of total response time to total errors	(TT/E)
11.	Ratio of total response time to total responses. . .	(TT/TR)
12.	Ratio of total responses to total errors	(TR/E)
13.	Equivocation rate while responding	(1.38138TR/TT)-(5/TT)

*Abbreviations employed are as follows: E for errors or resets, TT for total time, and TR for total responses.

[a]Identical to 3P-COTRAN measure # 7 (Alluisi & Morgan, 1968, Table 1, p. 14).

[b]Identical to 3P-COTRAN measure #5 (Alluisi & Morgan, 1968, Table 1, p. 14).

Table 2

Factor Loadings[#] of Thirteen Measures on Three Factors Extracted from Data of DR-COTRAN (and 3P-COTRAN) Performances

Measure Number	Factor I	Factor II	Factor III
1	-82 (-55)*	-43 (-67)	22 (12)
2	-93 (-97)*	-01 (07)	24 (-10)
3	-92 (-96)*	01 (03)	33 (-05)
4	-58 (-82)	02 (49)	55 (-07)
5	22 (-67)	95 (71)*	-07 (-00)
6	-71 (-90)	-07 (14)	50 (14)
7	38 (49)	85 (71)*	-28 (-15)
8	-19 (-16)	-10 (-10)	95 (95)*
9	72 (94)	05 (-09)	-65 (-23)
10	-39 (-18)	-16 (-31)	87 (89)
11	-28 (54)	-88 (-68)	07 (02)
12	-33 (-47)	-08 (-07)	93 (85)*
13	-57 (-86)	03 (44)	68 (04)

[#]Decimals omitted.

* Measures used in subsequent analyses to represent the factors.

Factor III is characterized by the high positive loadings of three error-related measures (numbers 8, 10, and 12), and it is identified as accuracy in problem solving; it corresponds essentially to factor III (errors in problem solving) as identified in previous studies of the 3P-COTRAN task (Alluisi & Coates, 1967, p. 19; Alluisi & Morgan, 1968, p. 17). High scores on this factor would be associated with a low number of errors (measure number 8), or with a high number of responses per error (measure number 12), and these two measures will be taken to represent factor III in subsequent analyses.

The high correlations obtained between the DR-COTRAN and 3P-COTRAN factors here, and the similarity between the current factors II and III and the two previously identified 3P-COTRAN factors III and IV, support the conclusion that the factorial nature of performance on the DR-COTRAN task is essentially identical to that of phase III in the 3P-COTRAN task. At least on this basis it appears reasonable to consider the use of either task as equivalent to the use of the other.

Experiment II

This second study was designed to measure the relative sensitivities of the 3P- and DR-COTRAN tasks to practice effects and to the effects of infectious disease. The performances of subjects were measured prior to, during, and subsequent to illness with Sandfly fever (see Coates et al., 1969, especially Appendix E) in a cooperative study conducted at the U. S. Army Medical Research Institute of Infectious Diseases (USAMRIID), Fort Detrick, Frederick, Maryland.

Method

The five subjects in each of four crews or subgroups (Able and Baker crews of the BEID-4 and BEID-5 groups; cf. Coates et al., 1969) completed either nine 3P-COTRAN problems or 18 DR-COTRAN problems on each of 15 successive days. Prior to testing on the seventh day, the four experimental subjects in each crew were infected (Phlebotomus papatasi--a self-limiting, febrile, viral disease); the fifth subject in each crew was a double-blind control. Testing continued during incubation (days 7-9), illness (days 10-12), and recovery from the illness (days 13-15). Half of the subjects (the Baker crews) were tested during the morning hours (0900-1130), whereas the other half (the Able crews) were tested during the afternoon (1300 to 1530 hours). Half of the DR-COTRAN testing was in the morning (BEID-4) and half in the afternoon (BEID-5); likewise, half of the 3P-COTRAN testing was in the morning (BEID-5) and half in the afternoon (BEID-4). The data of the four crews or subgroups were combined: group II-DR consists of the ten subjects (eight experimentals and two controls), each of whom completed the 18 DR-COTRAN problems per day, and group II-3P consists of the ten subjects who completed the nine 3P-COTRAN problems daily.

Apparatus.--The apparatus was identical to that employed in Experiment I as previously described.

Subjects.--All twenty of the volunteer subjects were Army enlisted men assigned for duty at the Walter Reed Army Medical Center. The ten in BEID-4 ranged in age from 21 to 26, with a median of 23.5 years; the age range in BEID-5 was from 21 to 24, with a median of 23.0 years. The division of the subjects into the five-man crews was random.

Procedure.--The experiment was conducted in two adjacent rooms (approximately 7-by-12 ft.) of a hospital ward at the USAMRIID, Fort Detrick. The subject and his apparatus occupied one room in which an overhead florescent light fixture provided ambient illumination; the experimenter's apparatus was in the adjoining room. Approximately 70 dB of broad-band noise were used in the subject's room to isolate it from extraneous sounds. As shown in Figure 4, the subject faced the apparatus as he occupied a bed in a semi-seated position during the experimental sessions.

Figure 4.--Schematic representation of subject in the semi-seated bed position occupied during 3P-COTRAN and DR-COTRAN (shown) testing in Experiment II.

Each subject experienced a training session on the day prior to the beginning of his 15-day period of testing. During this session the subject was instructed as to how to solve the problems of the type to which he and his crew or subgroup had been assigned; these instructions have been reproduced exactly elsewhere (for 3P-COTRAN in Morgan, 1968; for DR-COTRAN in Dempsey, 1969). Also, the subject was required to solve from three to five practice problems during this training session. In other regards, the procedure was essentially identical to that of Experiment I.

Results and Discussion

The data, consisting of the thirteen measures previously identified and defined in Table 1 (p. 11), were analyzed in two ways to permit inferences with regard to both illness and practice effects.

Illness effects.--Because of the small and unequal numbers of experimental and control subjects in each crew or subgroup (four and one, respectively), indirect statistical tests were employed to determine whether the illness produced measurable effects in the performances of either

version of the COTRAN task. Specifically, it was reasoned that were the illness to have produced a decrement in the performances of the four experimental subjects in each crew over the days of illness (sessions 10-12) with essentially no change in the performance of the control subject over the same sessions, then the variability of the performances among the five subjects in the crew should be increased during sessions 10, 11, and 12.

Root mean squares were computed--one for each of the thirteen measures on each of the fifteen testing sessions of each of the four crews--and these were then tested for statistically significant effects with an analysis of variance. For each of the thirteen measures, the results of the analysis of variance indicated that (1) DR-COTRAN performances were significantly (and substantially) less variable than 3P-COTRAN performances, and (2) in no case was there a significant increase in variability during the period of illness (sessions 10-12) relative to the pre- or post-illness periods.

Thus, the data indicate that the DR-COTRAN task is more reliable than the 3P-COTRAN task as employed in this study (18 DR- or 9 3P-COTRAN problems during a 20 to 30 min. session), but neither task is sufficiently sensitive when used alone to measure decrements in performance during the period of a subject's illness with a febrile disease such as Sandfly fever.

Practice effects.--Since no difference was found between experimental and control subjects during the period of illness, the data of the two were combined in these subsequent analyses. In addition to testing (a) for differences in performances across the 15 sessions, these analyses also tested (b) for differences in the performance levels obtained with the two versions of the COTRAN task, and (c) for any interaction of the sessions and task variables.

Of course, performance could differ across sessions as a result of the additional practice, or because of the illness and recovery of the experimental subjects, and the analyses had to be designed so as to isolate the different possible effects insofar as possible. The use of certain orthogonal comparisons permitted such isolation as described below.

A separate analysis of variance was computed for each of the thirteen measures of COTRAN performance. Whenever a statistically significant session-by-task interaction was found, the data were further analyzed to test for differences among the sessions separately for each task. Then, wherever statistically significant session effects were found, the data were still further analyzed with the following orthogonal comparisons:

Comparison No.	Sessions Compared	df
1	1-6 vs. 7-15	1
2	1-3 vs. 4-6	1
3	7-12 vs. 13-15	1
4	7-9 vs. 10-12	1
5	Residual Session Comparisons	10

Statistically significant results for comparison 1 could represent the effects of both practice and illness since the test compares the average performances over the first six sessions with those obtained over the last nine sessions, the latter's including the period of illness (sessions 10-12). On the other hand, significance for comparison 2 could result only from the effects of early practice--the first as compared with the second three sessions of COTRAN performances--and significance for comparisons 3 and 4 would most likely represent the effects of illness. Thus, the pattern of results obtained with these comparisons should prove helpful in seeking to understand the likely sources or causes of the more general "sessions" effects that were found to be statistically significant.

The results of the first (overall) analyses of variance indicated that the differences between the tasks were significant with twelve of the thirteen measures of COTRAN performance, and in each case LR-COTRAN performance was better than 3P-COTRAN (measure 8 did not yield significance; F = 90.90; 655.06; 91.36; 102.72; 1041.16; 53.78; 1358.38; 9.17; 128.11; 5.78; 1017.95; 44.71; 33.02; for measures 1-13, respectively; df = 1/240, $P<.05$ in each significant case). The differences among the fifteen sessions were significant in every case (F = 6.73; 25.61; 6.11; 8.18; 8.01; 2.67; 13.18; 3.18; 7.79; 4.50; 18.95; 6.68; 2.70; for measures 1-13, respectively; df = 14/240, $P<.01$ in each case). The tasks-by-sessions interaction was significant with all except two of the measures (measures 7 and 8; F = 5.15; 11.84; 5.07; 5.63; 3.08; 2.74; 1.67; 1.29; 6.11; 2.09; 4.75; 2.96; 2.63; for measures 1-13, respectively; df = 14/240, $P<.05$ for each significant case).

The statistically significant interactions obtained with the eleven measures were further analyzed separately for each version of the COTRAN task by computation of the previously described orthogonal comparisons. A summary of the results of these analyses for the 3P-COTRAN task is presented in Table 3; the corresponding summary for the DR-COTRAN task is given in Table 4. In examining the data of Tables 3 and 4, it should be remembered that the first three measures represent the general problem-solving factor, measures 5 and 7 represent the factor of speed in problem-solving, and measures 8 and 12 represent the factor of accuracy in problem solving (cf. results of Experiment I, pp. 10-12).

A comparison of the two tables suggests that the 3P-COTRAN task was somewhat more sensitive than the DR-COTRAN task to practice effects; the over-all "sessions" effects were statistically significant with eleven measures in the case of 3P-COTRAN, but only five measures with DR-COTRAN.

Table 3

Summary[#] of Analyses of Variance, With Orthogonal Comparisons, of 3P-COTRAN Performances

Measure Number	Source of Variation: Overall Sessions (df=14)	Orthogonal Comparison Number[♯] 1 (df=1)	2 (df=1)	3 (df=1)	4 (df=1)	Residual (df=10)	Within Cells (Mean Square[1]) (df=120)
1	19.51***	140.20***	85.93***	0.29	0.01	4.67***	8709.63
2	5.71***	45.61***	27.28***	0.05	0.06	---	333.45
3	6.13***	51.35***	26.53***	0.03	0.11	---	1037.05
4	2.97***	27.86***	9.84***	0.00	0.25	3.66***	0.11
5	2.54**	14.14***	2.18	2.20	2.69	1.68	0.37
6	7.34***	62.96***	27.97***	0.00	0.14	1.16	0.39
9	7.50***	68.57***	25.26***	0.01	0.16	1.10	0.05
10	4.79***	27.22***	22.27***	0.08	0.00	1.74	2895.48
11	12.33***	73.21***	38.05***	1.25	0.01	6.01***	85.28
12	4.36***	32.80***	15.13***	0.14	0.06	1.29	70.35
13	3.09**	30.39***	8.38**	0.02	0.53	---	0.74

Data are F-ratios (or Mean Squares); no analysis was computed in cases of measures #7 and #8 since the original analysis of variance had not resulted in statistically significant tasks-by-sessions interactions with these measures.

♯ See text, p. 16, for explanation and interpretation of the comparisons.

**p <.01, ***p <.001

[1]Mean Squares multiplied by 100

Table 4

Summary# of Analyses of Variance, With Orthogonal Comparisons, of DR-COTRAN Performances

Measure Number	Source of Variation: Overall Sessions (df=14)	Orthogonal Comparison Number ≠ 1 (df-1)	2 (df-1)	3 (df-1)	4 (df-1)	Residual (df=10)	Within Cells (Mean Square[1]) (df=120)
1	9.22***	57.66***	30.85***	0.69	1.85	3.80***	7665.85
2	1.15	---	---	---	---	---	89.99
3	1.54	---	---	---	---	---	457.29
4	0.32	---	---	---	---	---	0.13
5	6.09***	58.72***	12.34***	1.02	1.96	1.12	20.53
6	1.05	---	---	---	---	---	0.25
9	1.89*	9.33**	0.66	0.38	2.05	14.10***	0.06
10	5.45***	22.78***	9.56**	0.32	1.81	4.18***	1584.16
11	8.88***	62.71***	27.00***	0.49	1.49	3.26***	136.72
12	1.47	---	---	---	---	---	407.73
13	0.52	---	---	---	---	---	1.48

Data are F-ratios (or Mean Squares); no analysis was computed in cases of measures #7 and #8 since the original analysis of variance had not resulted in statistically significant tasks-by-sessions interactions with these measures.

≠ See text, p. 16, for explanation and interpretation of the comparisons.

* $P < .05$, ** $P < .01$, *** $P < .001$

[1]Mean Squares multiplied by 1000

Since the results were statistically significant with at least one measure from each of the three performance factors, even in the case of DR-COTRAN, it is concluded that the descriptive factors are equally sensitive, at least to the effect of practice or continued performance over 15 sessions.

The results of the orthogonal comparisons presented in Tables 3 and 4 indicate that where statistically significant session effects were found they resulted from practice effects rather than from the subject's illness. Comparisons 1 and 2 were statistically significant in all except two such cases (measures 5 in Table 3, and 9 in Table 4), whereas comparisons 3 and 4 failed to yield any significant results. This is further confirmation of the earlier conclusion that the experimental subjects did not differ from the controls in their levels of performance during the period of illness.

The general pattern of results and conclusions regarding the effects of illness and practice was essentially identical for the two versions of the COTRAN task, and it is obviously reasonable to continue to investigate the conditions under which either the 3P-COTRAN or the DR-COTRAN task might be employed as the test of choice.

It was concluded earlier that neither task is sufficiently sensitive when used alone to measure decrements in COTRAN performance during a subject's illness with a febrile disease such as Sandfly fever (emphasis added). Decrements in work behavior--in the multiple-task performances of these same subjects--were measured during the same period of illness reported here (cf. Coates et al., 1969). However, each subject performed the COTRAN task alone and for only 20 to 30 min. per day in the present study, whereas they were called upon to perform the multiple tasks in the sustained performance tests for two 4-hr. periods on each day. Thus, the 3P- or DR-COTRAN "test" situations apparently failed to produce the kind of sensitivity that is found in work-behavior situations and that is necessary for measuring the effects of stresses such as fatigue, sleep loss, and illness. This is consistent with the observation that test and work situations "appear to be differentially sensitive to temporal influences and stressful conditions" (Alluisi, 1969, p. 22). Under appropriate conditions, for example when included as one of the tasks in a multiple-task performance (MTP) battery, either 3P- or DR-COTRAN might be of optimum sensitivity. The two tasks do differ, not only in that one has three phases and the other only one phase (equivalent to the third phase of 3P-COTRAN), but also in 3P-COTRAN's being more difficult and showing effects of practice over a longer period and with more measures of performance, or in DR-COTRAN's being easier and more easily learned.

Experiment III

Although the results of the two previous experiments indicate that the two versions of the COTRAN task differ in certain ways (especially ways related to difficulty, ease of learning, and levels of performance attained), the studies did not suggest any essential difference between the two versions of the task. It seems appropriate, therefore, to

investigate further the characteristics of the DR-COTRAN task by using it in a partial replication of a previous study of the 3P-COTRAN task (Alluisi & Morgan, 1968).

This third experiment in the present series was conducted in order to measure the acquisition of skill on the DR-COTRAN task and the influence of practice on the nonverbal mediational aspects of intellectual functioning measured with the task. Specifically, this study was designed to answer two major and one minor questions as follows:

- What is the factorial structure of DR-COTRAN performance, and how does the structure change (if at all) during the acquisition of skill on this task?
- What are the effects of practice on nonverbal mediation as measured with the DR-COTRAN task?
- (The minor question.) Is transformation complexity a significant variable during the acquisition of skill on the DR-COTRAN tasks?

In addition, since these questions are similar to those investigated previously with respect to the 3P-COTRAN task (Alluisi & Morgan, 1968), it is expected that comparisons of the results of the two studies will provide further information regarding the use of the DR-COTRAN version as an alternative to the 3P-COTRAN version of the task.

Method

Each of 20 subjects was tested individually during four sessions, in each of which he completed 27 DR-COTRAN problems. The 27 problems in each session were divided into nine blocks of three problems each, and each block consisted of one three-, four-, and five-element transformation to permit measurement of any effects attributable to transformation complexity. The transformation complexities were counterbalanced across the block of trials, of course, to control for any possible order effects.

Apparatus.--The apparatus was identical to that of DR-COTRAN employed in Experiment I as previously described.

Subjects.--The subjects were 20 undergraduate male students at the University of Louisville. They were volunteers obtained by written request from the Naval and Air Force ROTC units, and they were paid for their participation in the experiment. The subjects ranged in age from 18 to 25, with a median of 20 years.

Procedure.--Except as noted below, the procedure was essentially identical to that of the DR-COTRAN performances of Experiment I. Adjacent subject and experimenter rooms were again used, but in the present case the subject's room was an acoustically treated booth of 6-by-7.5 ft. dimensions.

The four sessions for each subject were presented on two successive days, two sessions per day separated by a 5-min. rest interval. During his first session, each subject was instructed regarding the nature of the task and the performance required of him (cf. Dempsey, 1969, Appendix A). He then solved the 27 problems assigned to that session, and after the 5-min. rest interval, the second session began and the subject was required to complete the second set of 27 DR-COTRAN problems. The initial session was typically of about 35-min. duration; subsequent sessions lasted between 15 and 25 min.

Results and Discussion

A separate set of analyses was computed for each of the three questions previously listed. The first set consisted of 52 factor analyses--one for each of the thirteen measures of performance in each of the four performance sessions. The second set of analyses was directed at the identification of any evidenced practice effects associated with the acquisition of skill in solving DR-COTRAN problems; this set consisted of seven analyses of variance--one for each of the seven measures of DR-COTRAN performance selected to represent the three problem-solving factors measured by the task. The third, and final, set of analyses was designed to measure the effects (if any) of transformation complexity at various levels of practice or skill acquisition; this set consisted of 28 analyses of variance--one for each of the seven measures of performance in each of the four performance sessions. The thirteen measures of DR-COTRAN performance were those previously identified and defined in Table 1 (p. 11). The three sets of analyses are presented and discussed separately below.

Factor analyses.--An IBM-1130 statistical system program was employed in the computation of the factor analyses (principle-axis method with the highest off-diagonal correlation as the estimate of communality), and in the rotation of the extracted factors according to the Varimax criterion. The loadings of the thirteen measures on each of the three extracted and rotated factors are given in Table 5 for each of the four sessions. The percentages of total variance accounted for by each of the three factors are given in Table 6 for each of the four sessions.

The data of Table 5 indicate that the three factors were essentially identical over the four sessions. The coefficients of correlation obtained for each of the three factors between the loadings of the six different pairings of the four sessions (18 coefficients in all) ranged between +.976 and +.998 ($df = 11$, $P < .001$ in each case). It is concluded that there is no evidence of any change in factor structure over the four sessions.

This conclusion is further supported by the results of an additional correlational analysis. In this case, the coefficients of correlation obtained for each of the three factors between the loadings of DR-COTRAN in Experiment I (see Table 2, p. 12) and the four sessions here (Table 5) ranged between +.954 and +.996 ($df = 11$, $P < .001$ in each case of the 12 cases). Thus, the three factors can be identified as identical to those of Experiment I (cf. pp. 8-12); namely, Factor I represents general problem solving, Factor II speed in problem solving, and Factor III

Table 5

Loadings[≠] of Thirteen Measures of DR-COTRAN Performance on Three Problem-Solving Factors over Four Skill-Acquisition Sessions of 27 Problems Each

Measure Number (& Factor)	Factor I Session 1	I 2	I 3	I 4	II Session 1	II 2	II 3	II 4	III Session 1	III 2	III 3	III 4
1(I,II)*	-52	-72	-55	-77	-65	-56	-70	-53	24	25	32	18
2(I)*	-92	-93	-95	-97	-19	-20	-13	-15	25	25	22	14
3(I)*	-79	-84	-83	-90	-18	-17	-15	-14	41	45	46	35
4(I)	-84	-73	-89	-78	-06	-11	-10	-10	45	57	41	48
5(II)*	00	05	01	06	98	98	94	99	-03	-03	-02	-02
6(I)	-88	-82	-89	-87	-17	-21	-14	-14	39	44	40	37
7(II)*	27	32	28	29	90	83	90	88	-24	-35	-25	-28
8(III)*	-37	-26	-34	-21	-10	-11	-11	-09	91	95	92	96
9(I)	76	72	74	75	16	16	15	13	-58	-65	-63	-62
10(III)	-39	-38	-39	-31	-21	-21	-17	-15	84	87	88	91
11(II)	-05	-17	-01	-13	-95	-96	-98	-97	04	05	02	04
12(III)*	-44	-34	-40	-20	-12	-11	-12	-09	88	93	90	95
13(I,III)	-73	-60	-72	-62	-05	-06	-10	-06	58	72	64	69

≠ Decimals omitted

* Measures used in subsequent analyses to represent the factors.

Table 6

Percentages of Total Variance Explained by Each of Three Problem-Solving Factors Over Four Skill-Acquisition Sessions of 27 DR-COTRAN Problems Each

Factor	Session			
	1	2	3	4
I	69.99%	72.44%	70.00%	67.00%
II	21.44	19.10	21.79	20.41
III	7.10	8.06	7.93	11.70
Total	98.53%	99.60%	99.72%	99.20%

accuracy in problem solving. The seven measures previously selected to represent the three factors (in Experiment I) are identified with asterisks in Table 5. These measures are employed in the subsequent analyses.

Practice effects.--The effects of practice (four sessions of 27 problems each) on DR-COTRAN performances were assessed with single-factor analyses of variance computed with the data of each of the seven measures. Statistically significant between-sessions effects were indicated for the data of measures 1 (Factors I & II; Figure 5), 5 and 7 (Factor II; Figure 6), and measure 12 (Factor III; Figure 7); the F ratios were 74.52, 146.74, 147.98, and 3.34, respectively ($df = 3/57$, $P < .001$ in the first three cases, and $P < .05$ for measure 12). Each data point in Figures 5 through 7 is an arithmetic mean of the performances of the 20 subjects each of whom completed 27 problems, and, therefore, each is based on a total of 540 DR-COTRAN solutions.

In order to permit identification of the sessions beyond which no further gains in performance took place with practice, Newman-Keuls analyses were computed with the data of the four significant measures shown in Figures 5 through 7.

In Figure 5, total response time appears to be a negatively accelerated decreasing function of practice. The Newman-Keuls analysis indicated that there were statistically significant gains in performance to session 3, but no significant changes in total response time beyond session 3. The two

Figure 5.--Mean total response time (TT, measure number 1) as a function of practice over four sessions of 27 DR-COTRAN problems each. This measure represents factors I and II, the general and speed factors.

measures that represent Factor II, the speed in problem-solving factor (Figure 6), appear to show fairly linear increases in speed with practice, and the Newman-Keuls analyses of these measures indicated that there were statistically significant gains in performances with both measures through all four sessions. Finally, the ratio of responses to errors (measure 12, Figure 7) showed increased accuracy in problem solving between sessions 1 and 2, then a drop to session 3, which the Newman-Keuls analysis showed not to be different from session 4.

In general, the results of Newman-Keuls analyses computed with all seven measures suggest that as measured with the five general and accuracy scores (measures 1, 2, 3, 5, and 7, representing Factors I and II) DR-COTRAN performance reached asymptotic levels during or prior to session 3 (problem solutions number 55 through 81). Performance as measured with the two speed scores (measures 8 and 12, representing Factor III) did not reach an asymptotic level within the limits of practice provided in this study (108 problems).

Figure 6.--Mean ratio of total responses to total response time (TR/TT, measure number 5) and mean reciprocal of total response time (1/TT, measure number 7) as functions of practice over four sessions of 27 DR-COTRAN problems each. These measures represent factor II, speed in problem solving.

Figure 7.--Mean ratio of total responses to total errors (TR/E, measure number 12) as a function of practice over four sessions of 27 DR-COTRAN problems each. This measure represents factor III, accuracy in problem solving.

Effects of transformation complexity.--An analysis of variance was computed with the data of each of the seven measures for each of the four sessions in order to permit an assessment of the effects of transformation complexity on DR-COTRAN performance at the different levels of skill acquisition. The results of these analyses are presented for sessions 1 through 4 in Tables 7 through 10, respectively.

Transformation complexity produced statistically significant effects in the cases of (a) measure 1 during sessions 2, 3, and 4, and (b) measures 5 and 7 during each of the four sessions. It may be recalled that measure 1 is loaded on Factors I and II, while measures 5 and 7 represent solely Factor II, the speed in problem-solving factor. The data of these measures are given in Figures 8 and 9.

Table 7

Summary of Analyses of Variance of Seven DR-COTRAN Measures: Data of Session 1.

Measure Number (and Factor)	Source of Variation (and df)				
	Transformation Complexities (2)		Subjects (19)		Residual (38)
	Mean Square	F	Mean Square	F	Mean Square
1 (I,II)[3]	1.0000	---	15.2167	2.6161**	5.8166
2 (I)	0.9500	---	2.1851	---	2.9851
3 (I)	17.2500	---	17.2434	---	24.8125
5 (II)[1]	6.0767	12.5108***	11.7629	24.2180***	0.4857
7 (II)[2]	1.7319	5.3214**	4.3551	13.3816***	0.3255
8 (III)	0.8350	1.8225	0.8784	1.9172*	0.4582
12 (III)	67.7532	2.0063	51.4716	1.5242	33.7699

*P <.05, **P <.01, ***P <.001

[1]Mean squares multiplied by 10

[2]Mean squares multiplied by 100

[3]Mean squares divided by 100

Table 8

Summary of Analyses of Variance of Seven DR-COTRAN Measures: Data of Session 2

Measure Number (and Factor)	Source of Variation (and df)				
	Transformation Complexities (2)		Subjects (19)		Residual (38)
	Mean Square	F	Mean Square	F	Mean Square
1 (I,II)[3]	7.2416	4.6126*	17.4195	11.0956***	1.5700
2 (I)	1.0500	---	7.9254	2.0832*	3.8044
3 (I)	6.8125	---	38.7039	1.5486	24.9934
5 (II)[1]	13.9954	44.7116***	16.8328	53.7767***	0.3130
7 (II)[2]	5.7236	20.1667***	6.9969	24.6531***	0.2838
8 (III)	0.3050	---	0.7245	1.0892	0.6651
12 (III)	25.6646	---	55.4052	1.0624	52.1502

*p <.05, ***p <.001

[1]Mean squares multiplied by 10

[2]Mean squares multiplied by 100

[3]Mean squares divided by 100

Table 9

Summary of Analyses of Variance of Seven DR-COTRAN Measures: Data of Session 3

Measure Number (and Factor)	Source of Variation (and df)				
	Transformation Complexities (2)		Subjects (19)		Residual (38)
	Mean Square	F	Mean Square	F	Mean Square
1 (I,II)[3]	8.1388	9.1980***	6.1464	6.9464***	0.8848
2 (I)	4.1167	2.3303	2.1500	1.2176	1.7658
3 (I)	15.6563	1.5252	15.0263	1.4639	10.2648
5 (II)[1]	28.3655	41.6630***	18.0478	26.5084***	0.6808
7 (II)[2]	12.7556	26.8726***	7.2397	15.2522***	0.4747
8 (III)[1]	0.8481	---	5.0850	1.6633	3.0572
12 (III)	8.1904	---	37.7191	1.6498	22.7257

***p <.001

[1]Mean squares multiplied by 10

[2]Mean squares multiplied by 100

[3]Mean squares divided by 100

Table 10

Summary of Analyses of Variance of Seven DR-COTRAN Measures: Data of Session 4

Measure Number (and Factor)	Source of Variation (and df)				
	Transformation Complexities (2)		Subjects (19)		Residual (38)
	Mean Square	F	Mean Square	F	Mean Square
1 (I,II)[3]	5.6363	3.5751*	7.6761	4.8689***	1.5765
2 (I)	0.8167	---	5.6456	---	6.2377
3 (I)	0.7188	---	19.0954	1.0051	18.9984
5 (II)[1]	43.0310	63.7815***	22.3228	33.0813***	0.6747
7 (II)[2]	16.6206	37.9217***	8.5958	19.6121***	0.4383
8 (III)	0.1738	---	0.4046	1.9880*	0.2035
12 (III)	8.1938	---	30.9188	2.2499*	13.7420

*P <.05, ***P <.001

[1]Mean squares multipled by 10

[2]Mean squares multipled by 100

[3]Mean squares divided by 100

Figure 8.--Mean ratio of total responses to total response time (TR/TT, measure number 5) and mean reciprocal of total response time (1/TT, measure number 7) at three levels of transformation complexity as functions of practice over four sessions of nine DR-CUTRAN problems of each complexity. These measures represent factor II, speed in problem solving.

Figure 9.--Mean total response time (TT, measure number 1) for problems at three levels of transformation complexity as a function of practice over four sessions of nine DR-COTRAN problems of each complexity. This measure represents factors I and II, the general and speed factors.

It is apparent from the figures that the differential effects of the three levels of transformation complexity were generally greater during sessions 3 and 4 (after practice) than during sessions 1 and 2 (at the beginning of practice). It is not known whether these differences would be maintained, lessened, or enlarged with further practice or with the attainment of asymptotic levels of performance as measured with these speed-of-response scores. However, this much is clear: transformation complexity does represent a significant aspect of problem difficulty associated with the speed of performing the DR-COTRAN task.

Experiment IV

The purpose of the fourth, and final, study in the present series was to measure the effects of operator loading on DR-COTRAN performance, and, conversely, the effects of adding the DR-COTRAN task on the performances of different combinations of tasks from the multiple-task performance

(MTP) battery. As was the case with Experiment III, the present study represents a partial replication of a previous study of the 3P-COTRAN task (Alluisi & Morgan, 1968), and a comparison of the results of the two studies are expected to provide further information regarding the use of the DR-COTRAN version as an alternative to the 3P-COTRAN version of the task.

Method

The 20 subjects who had been trained to solve DR-COTRAN problems in Experiment III were divided at random into five groups of four subjects each. Each group was then trained to perform in one of five different work-load conditions created by the use of different combinations of tasks from the MTP battery (three sessions of 30-min. duration each). After this, each subject was required to solve 27 DR-COTRAN problems in each of three sessions during which he was also required to perform concurrently the MTP tasks of the specific work-load condition to which his group had been assigned and trained.

Apparatus.--The DR-COTRAN apparatus was identical to that employed in Experiment I as previously described. In addition, the MTP battery was employed--the operator panel by the subjects and the necessary programming and scoring equipment by the experimenter.

As indicated previously in the introduction (pp. 1-3), six tasks can be presented with the MTP battery. The tasks are displayed on an operator panel like that pictured in Figure 1 (p. 2) and shown schematically in Figure 10. Since all the tasks have been described previously, they will be identified here without repetition of the full descriptions given elsewhere (Adams & Chiles, 1960; 1961; Alluisi, 1969; Alluisi & Chiles, 1967; Alluisi et al., 1962; 1963; 1964; 1967; Chiles et al., 1968).

Three tasks are used to measure the operator's performance of watchkeeping, vigilance, and attentive functions (blinking-lights, warning-lights, and probability monitoring). These tasks require the operator to respond to the relatively infrequent occurrence of changes in the states of certain visual displays. In the warning-lights task (located at the extreme left of the panel), the operator is required to respond by turning a green warning light on should it go off, and a red warning light off should it go on. Blinking-lights monitoring (located at the extreme right) requires that he respond to an arrest of alternation of the blinking of the two amber lights. The probability-monitoring task (presented by the four meters along the top of the panel) is somewhat more difficult than the other two watchkeeping tasks. It requires an integration over time of random fluctuations of the pointers on the four semicircular scales. The pointer settings are normally distributed with a mean of zero (12:00 o'clock); the operator is required to respond to relatively infrequent shifts in the mean of this distribution.

Figure 10.--Schematic diagram of the front view of an MTP operator, panel. Letters in circles represent indicator lights, A--Amber, B--Blue, G--Green, and R--Red: the smaller circles with crossing diagonals represent push-buttons.

The remaining three tasks are used to measure memory functions (arithmetic computations), sensory-perceptual functions (target identifications), and procedural functions (code-lock solving). The code-lock solving task was not used and will not be discussed here.

The arithmetic-computation (MATH) task (located along the bottom of the panel) presents a horizontal display of three, 3-digit numbers, or nine digits in all. The operator is required to add the first 3-digit number to the second, and then to substract the third 3-digit number from the sum. No memory aid is permitted, and the task is forced-paced at a rate of three problems per minute.

The target identification (TID) task (located in the center of the panel) presents a "target" image which resembles a solid bar graph, then successively two similar "choice" images (either or both of which might be rotated 0, 90, 180, or 270 deg. from the normal positioning of the target). The operator judges whether the first, the second, or neither of the two choice images is the same as the previously displayed target image, irrespective of orientation. This task is forced-paced at a rate of two problems per minute.

Subjects.--The 20 subjects of Experiment III (cf. page 21) were divided at random into five groups of four subjects each.

Procedure.--Except as noted herein, the experimental conditions were identical to those of Experiment III. The appropriate elements of the MTP battery were installed in the subject and experimenter rooms; the arrangement of the DR-COTRAN apparatus and the MTP operator panel in the subject's room is shown in Figure 11.

Each subject served for a total of six sessions, two on each of three successive days. During the first three sessions (each of which was of exactly 30-min. duration), he was required to perform the tasks of the MTP battery which had been assigned as the work-load condition for his group. During each of the second three sessions (approximately 30-min. duration each), he was required to solve 27 DR-COTRAN problems while concurrently performing the MTP tasks of his work-load condition.

Figure 11.--Photograph of the arrangement of the DR-COTRAN apparatus and MTP operator panel in Experiment IV. The MTP operator panel is located in the center, the DR-COTRAN information panel on the left, and the response key and information feedback panel on the right as the subject faced the equipment.

The five work-load conditions were identical to those employed in the previous study of 3P-COTRAN performance (Alluisi & Morgan, 1968); namely, (1) the three watchkeeping or passive tasks (warning-lights, blinking-lights, and probability monitoring), (2) target identifications (TID), (3) arithmetic computations (MATH), (4) the passive tasks plus TID, and (5) the passive tasks plus MATH. These combinations of tasks represent increases in the amount of "cognitive processing" required of the subjects. Since DR-COTRAN performance, like 3P-COTRAN performance, is largely problem-solving behavior dependent on the nonverbal mediational aspects of intellectual functioning, the increased time-sharing requirements placed on the subjects were expected to produce detrimental effects at some point(s) along the dimension of the work-load condition.

Prior to the beginning of the first session, each subject was familiarized with the MTP task(s) assigned to his group. Instructions were given separately for each task, and the subject was permitted to work from three to five familiarization problems prior to the beginning of the experimental session. A 5-min. rest interval separated the two completed sessions on a given day. Prior to the fourth session, the subject was reminded that he was henceforth required to solve DR-COTRAN problems concurrently with performance of the MTP tasks.

Results and Discussion

The performance of both of DR-COTRAN task and the assigned combinations of tasks from the MTP battery were recorded and have been analyzed. In order to assess more fully the effects of the work-load conditions on DR-COTRAN performances, the data of the fourth session of Experiment III were included in certain of the analyses of the present study; these data have been identified herein as those of "session PT" (for "Pre-Test").

Effects of DR-COTRAN on multiple-task performances.--Performances of the several tasks from the MTP battery were scored as follows: (a) mean normalized speed of correct responses to green warning lights, (b) red warning lights, and (c) blinking lights, (d) percentage of probability-monitoring signals detected, and (e) mean speed in making such detections, (f) percentage correct of problems attempted in the TID task and (g) in the MATH task, (h) percentage of TID problems attempted, and (i) percentage of MATH problems attempted. These are measures typically employed in the scoring of these tasks (cf. Alluisi, 1969; Alluisi & Morgan, 1968; Chiles et al., 1968).

The mean of the performances obtained in sessions 1, 2, and 3 was then computed for each measure (and each subject), and this score was compared with that obtained in each of the subsequent three sessions during which the DR-COTRAN task was concurrently performed. Several analyses of variance were computed--one for each of the MTP-battery measures. Statistically significant effects occurred only in the cases of the two measures of performances with the probability-monitoring task. As shown in Table 11, the differences among the three levels of work-load (passive tasks only, passive tasks and TID, passive tasks and MATH) were statistically significant. Neither the sessions effects nor

Table 11

Summary of Analyses of Variance of the Two Measures of Probability-Monitoring Performance#

Source of Variation	df	Accuracy Mean Square[1]	Accuracy F	Speed Mean Square[2]	Speed F
Work-Load Conditions (W)	2	74.9709	5.4928*	128.6703	7.4535*
Within W (Error 1)	9	13.6489	---	17.2632	---
Sessions (S)	3	1.2194	---	1.5389	---
W-by-S Interaction	6	3.5658	1.5583	2.9545	1.4156
Residual (Error 2)	27	2.2884	---	2.0871	---

#The percentages of probability-monitoring signals correctly detected, or "accuracy," and the mean speed in making such detections.

*$P < .05$

[1]Mean squares divided by 100

[2]Mean squares divided by 1000

the interaction of sessions with work-load conditions was significant in this (or any other) analysis.

The data pertaining to these two scores of probability-monitoring performances are given in Figures 12 and 13. It is apparent that the condition of concurrent performances of the passive and MATH tasks resulted in poorer accuracy (Figure 12) and speed (Figure 13) than was obtained under the other two conditions (passives alone, or passives plus TID). The lack of any general differentiation between the sessions with concurrent DR-COTRAN problems (sessions 4, 5, 6) and those without DR-COTRAN (sessions 1, 2, 3), along with the results of the analyses of variance cited in the preceding paragraph, lead to the conclusion that the addition of the DR-COTRAN task to combinations of MTP-battery tasks will not adversely affect performances on those tasks.

Figure 12.--Mean percentage of probability monitoring signals correctly detected under three work-load conditions over six 30-minute sessions. The average of sessions 1-3 (first point) represents performance with MTP-battery tasks only; 27 DR-COTRAN problems were concurrently solved during each of the remaining three sessions (4, 5, and 6).

Effects of work-load on DR-COTRAN performances.--Performances of the DR-COTRAN task were scored with the seven measures selected in Experiment III to represent the three problem-solving COTRAN factors (cf. Table 5, p. 22). Then, a two-factor analysis of variance was computed with the data of each measure. One dimension of the analysis consisted of the four sessions of DR-COTRAN performance (sessions PT, 4, 5, and 6), and the other consisted of the five levels of the work-load conditions--i.e., the five combinations of MTP-battery tasks time-shared with DR-COTRAN during the last three sessions; namely, (a) the passive tasks alone, (b) TID, (c) MATH, (d) passive tasks plus TID, and (e) passive tasks plus MATH. Furthermore, whenever statistically significant work-load effects were discovered, the basic analyses were extended with orthogonal comparisons as follows (df = 1 for each comparison):

Figure 13.--Mean speed in correctly detecting probability-monitoring signals under three work-load conditions over six 30-minute sessions. The average of sessions 1-3 (first point) represents performance with MTP-battery tasks only; 27 DR-COTRAN problems were concurrently solved during each of the remaining three sessions (4, 5, and 6).

Comparison Number	Work-Load Conditions Compared	General Meaning of the Specific Comparison
1	(a) vs. (b,c,d,e)	Passives alone vs. active tasks and passives with actives
2	(b,d) vs. (c,e)	TID vs. MATH
3	(b) vs. (d)	TID: alone vs. with passives
4	(c) vs. (e)	MATH: alone vs. with passives

Wherever statistically significant sessions effects were discovered, the basic analyses were extended with additional orthogonal comparisons as follows (df = 1 for each comparison):

Comparison Number	Sessions Compared	General Meaning of the Specific Comparison
5	(PT) vs. (4,5,6)	DR-COTRAN alone vs. time-shared
6	(4) vs. (5,6)	First vs. subsequent time-shared sessions
7	(5) vs. (6)	Penultimate vs. final time-shared sessions

Finally, all significant interactions were further analyzed with the appropriate orthogonal comparisons for the between-sessions effects at each level of the work-load conditions.

The analyses of variance indicated that statistically significant effects were obtained only with measures number 1 (TT, Factors I & II; Figure 14), number 5 (TR/TT, Factor II; Figure 15), and number 7 (1/TT, Factor II; Figure 15). The results of the analyses of these three measures are summarized in Table 12. The effects of the sessions variable, and the interaction of work-loads and sessions, were statistically significant with all three measures, as were orthogonal comparisons numbers 5 and 6. The effects of the work-load conditions, as well as orthogonal comparisons numbers 1 and 7, were statistically significant with measures number 5 and number 7, the two measures that represent Factor II, the speed in problem-solving factor.

The data of these three measures are presented in Figures 14 and 15. A summary of the orthogonal comparisons of the effects of the sessions taken for each of the five work-load conditions is given in Table 13. These comparisons are, of course, more detailed than the general comparisons of the over-all analyses that were given in Table 12; in conjunction with the data presented in Figures 14 and 15, these results lead to the following conclusions.

(a) Time-sharing the DR-COTRAN task with only the three passive tasks of the MTP battery has no immediate nor long-term effect on DR-COTRAN performances. (b) Time-sharing with the TID task (either alone or in combination with the passive tasks) produced immediate decrements in the speed (Factor-II) aspects of DR-COTRAN performances, with no indications of statistically significant recovery with practice over three sessions of 27 problems each. Finally, (c) time-sharing with the MATH task (either alone or in combination with the passive tasks) also produced immediate decrements in the speed (Factor-II) aspects of DR-COTRAN performances, but statistically significant recovery appeared to start nearly immediately and to continue through the three sessions of 27 problems presented; recovery was not complete, however, and apparently additional practice would be necessary to reach an asymptotic level either equal to or below (or, perhaps, even above) the pre-work-load level.

Table 12

Summary of Analyses of Variance (and Orthogonal Comparisons) of DR-COTRAN Measures Number 1 (TT), 5 (TR/TT), and 7 (1/TT)

Source of Variation (& Orthogonal Comparison No.)	df	Measure 1		Measure 5		Measure 7	
		Mean Square[a]	F	Mean Square[b]	F	Mean Square[c]	F
Work-Loads (W)	4	16.2312	2.74	12.5378	4.16*	48.1190	4.00*
(Comp. 1)	(1)	---	---	33.4390	11.90**	125.0681	10.38**
(Comp. 2)	(1)	---	---	3.2744	1.09	12.7474	1.06
(Comp. 3)	(1)	---	---	12.0087	3.98	48.4638	4.02
(Comp. 4)	(1)	---	---	1.3927	---	6.6160	---
Within W (Error)	15	5.9178	---	3.0147	---	12.0440	---
Sessions (S)	3	16.3510	27.93***	11.5728	63.63***	45.6625	71.31***
(Comp. 5)	(1)	40.4344	69.07***	28.3904	156.11***	114.7873	179.27***
(Comp. 6)	(1)	6.3838	10.91**	5.1439	28.28***	17.3977	27.17***
(Comp. 7)	(1)	2.2212	3.79	1.1477	6.31*	4.7774	7.46**
W-by-S	12	1.3646	2.33*	0.7319	4.02***	2.8501	4.451***
Residual (Error)	45	0.5854	---	0.1819	---	0.6403	---

*p <.05, **p <.01, ***p <.001

[a]Mean squares divided by 1000

[b]Mean squares multiplied by 100

[c]Mean squares multiplied by 10,000

Figure 14.--Mean total response time (TT, measure number 1) for DR-COTRAN problems time-shared during sessions 4, 5, and 6 at five different work-load conditions--i.e., with five different combinations of tasks from the MTP battery.

General Discussion

The results of Experiments I and III indicated that DR-COTRAN performances could be adequately represented with three problem-solving factors identified as a general (Factor I), a speed (Factor II), and an accuracy (Factor III) factor. The second of these factors corresponds essentially to Factor IV, and the third to Factor V, of 3P-COTRAN problem solving (cf. Alluisi & Coates, 1967; Alluisi & Morgan, 1968). At least from this point of view, DR-COTRAN appears to measure the same nonverbal-mediational aspects of intellectual functioning as has been demonstrated to be measured with the 3P-COTRAN task.

The Varimax rotations of the factorial extractions in Experiment III produced essentially identical structures across the four sessions of practice in the acquisition of DR-COTRAN skill. Thus, like the 3P-COTRAN task (Alluisi & Morgan, 1968), the nature of DR-COTRAN performance as represented by its factor structure remains invariant during the acquisition of the problem-solving skill. This is another important characteristic shared by the 3P and DR versions of the COTRAN task. Also,

Figure 15.--Mean ratio of total response to total response time (TR/TT, measure number 5) and mean reciprocal of total response time (1/TT, measure number 7) for DR-COTRAN problems time-shared during sessions 4, 5, and 6 at five different work-load conditions--i.e., with five different combinations of tasks from the MTP battery.

Table 13

Summary of Orthogonal Comparisons of Session Effects at Each of Five Levels of Work-Load Conditions for DR-COTRAN Measures Number 1 (TT), 5 (TR/TT), and 7 (1/TT)[1]

Source of Variation (& Orthogonal Comparison No.)	df	Measure 1		Measure 5		Measure 7	
		Mean Square	F	Mean Square	F	Mean Square	F
Work-load Condition 1 (W1; passive tasks only)							
(Comp. 5)	(1)	4.602	---	2.771	---	.415	---
(Comp. 6)	(1)	.023	---	115.497	8.847*	27.311	4.222
(Comp. 7)	(1)	.303	---	17.461	1.338	12.466	1.927
Within W1 (Error)	9	5.047	---	13.055	---	6.468	---
Work-load Condition 2 (W2; TID only)							
(Comp. 5)	(1)	1138.880	36.220***	1028.805	26.938***	423.300	31.276***
(Comp. 6)	(1)	149.654	4.759	97.978	2.565	52.332	3.367
(Comp. 7)	(1)	31.668	1.007	10.493	---	6.122	---
Within W2 (Error)	9	31.444	---	38.191	---	13.534	---
Work-load Condition 3 (W3; MATH only)							
(Comp. 5)	(1)	744.539	15.055**	1208.776	132.629***	484.992	227.710***
(Comp. 6)	(1)	535.892	10.836**	99.670	10.936**	32.391	15.208**
(Comp. 7)	(1)	6.570	---	10.907	1.197	4.690	2.202
Within W3 (Error)	9	49.456	---	9.114	---	2.130	---
Work-load Condition 4 (W4; passive tasks with TID)							
(Comp. 5)	(1)	2496.087	13.928**	720.873	36.524***	284.729	43.991***
(Comp. 6)	(1)	130.152	---	59.844	3.032	17.270	2.668
(Comp. 7)	(1)	298.448	1.665	32.999	1.672	9.508	1.469
Within W4 (Error)	9	179.219	---	19.737	---	6.472	---
Work-load Condition 5 (W5; passive tasks with MATH)							
(Comp. 5)	(1)	843.772	30.640***	755.323	67.688***	286.704	84.207***
(Comp. 6)	(1)	91.312	3.316	152.505	14.038**	51.652	15.171**
(Comp. 7)	(1)	70.729	2.658	56.100	5.164*	17.653	5.185*
Within W5 (Error)	9	27.538	---	10.863	---	3.405	---

*P <.05, **P <.01, ***P <.001

[1]Mean square error terms for measure #1, #5, and #7 were multiplied by 10, 10,000 and 100,000, respectively.

this stability of structure--across experiments, times of measurements, subjects, and even the two versions of the task--removes at least one of the difficulties previously associated with the measurement of problem-solving behavior; namely, the difficulties associated especially with the "parlor-game" types of tasks employed nearly universally prior to 1950 in which widely variable results were likely within and between problems, individuals, and experimental conditions (cf. Ray, 1955). Indeed, it now appears possible with either version of the COTRAN task to study problem-solving behavior with the assumption that only one performance phenomenon is involved--the nonverbal mediation required in the application of a single principled rule.

Practice Effects

The percentages of explained variance accounted for by each of the three factors in Experiment III remained essentially constant across the four sessions of practice. Essentially identical results had been obtained previously with the 3P-COTRAN task (Alluisi & Morgan, 1968, p. 41). The COTRAN task, in either the 3P or DR version, is intellectual in nature, and perhaps this explains how it is that these results are contrary to those typically obtained in the study of psychomotor skills (cf. Fleishman & Hempel, 1956). In fact, this could be one of the important operational differentiations of the different kinds of skills involved!

The problem-solving skills involved in DR-COTRAN performances were improved with practice, but at differential rates according to the different factors and measures of performance employed; specifically, asymptotic levels of performance were reached at earlier stages of practice with the general and accuracy (or error) measures than with the speed (or time) measures. The results previously obtained with the 3P-COTRAN task were essentially identical: asymptotic levels of performance were reached with the error-related measures earlier than with the time-related (Alluisi & Morgan, 1968).

Practice and problem difficulty (as manipulated by use of the transformation-complexity variable) were found to interact in Experiment III; the interaction was essentially identical to that previously found with the use of the 3P-COTRAN task (Alluisi & Coates, 1967; Alluisi & Morgan, 1968). Specifically, the attainment of asymptotic levels of DR-COTRAN performances was affected inversely by transformation complexity and directly by the degree of practice provided. The three transformation-complexity levels (problems with 3, 4, or 5 transformations required) represented three distinct levels of performance (and, by inference, of difficulty) throughout the acquisition of the DR-COTRAN skill, and these differences appeared to be maintained when asymptotic levels of performance were attained. In this regard the DR-COTRAN task appears more sensitive than the 3P-COTRAN version since differences among the three transformation-complexity levels with thvt task did not emerge until asymptotic levels of performance had been reached. This is one of the few differences observed in the characteristics of the two versions of the COTRAN task, and although it does not appear to be an essential difference, it favors the DR-COTRAN version over the other task.

Sensitivity to Effects of Illness

The general pattern of results and conclusions regarding the effects of illness and practice in Experiment II was essentially identical for the two versions of the COTRAN task. Neither task was sufficiently sensitive when used alone in a 20 to 30-min. session daily to measure decrements in COTRAN performance during a subject's illness with a febrile disease such as Sandfly fever. However, since decrements in work behavior--in the MTP battery performances--of the same subjects were measured during the same periods of illness (cf. Coates et al., 1969), it is predicted that either task would be "appropriately sensitive" and would contribute to the general decrements in work behavior during illness if embedded as one of the tasks in the MTP battery rather than used alone. This prediction will have to await further tests for verification or denial.

The results of Experiment II also show some of the differences in the two versions of the COTRAN task. Not only are there the structural differences (one version has three phases, whereas the other has only one phase that is equivalent to the third phase of the former), but also there are important differences related to their application or use. The 3P-COTRAN task is more difficult and it shows the effects of practice over a longer period and with more numerous measures of performance than the DR-COTRAN version which is easier and more quickly learned. These differences, like those discussed in the previous section, are not essential, and for the most part they favor the DR-COTRAN task.

Combinations of DR-COTRAN With the MTP Battery

The results of Experiment IV indicate that the addition of the DR-COTRAN task to various combinations of tasks from the MTP battery does not adversely affect the performances of the latter. The more-difficult 3P-COTRAN version had been found in a previous study to be different in this regard; multiple-task performances were not maintained with concurrent work on the 3P-COTRAN task in the MATH and the passive-plus-MATH-work-load conditions (cf. Alluisi & Morgan, 1968, pp. 31-35). This difference again favors the DR-COTRAN version of the task for use with the other tasks in the MTP battery.

DR-COTRAN performances were essentially unafffected by the requirement that they be time-shared with only the three passive or watchkeeping tasks of the MTP battery. They were adversely affected (in terms of the speed scores) when time-shared with either of the active tasks (TID or MATH) whether alone or with the addition of the passive tasks. If and when the DR-COTRAN task is added to the MTP battery, therefore, consideration should be given to employing it under at least two work-load conditions, one of which is essentially unstressed (the passive tasks alone) and the other of which represents a work-load stress (the passive tasks plus TID or MATH).

General Conclusion

The results of the present studies, and those of the previous studies of the 3P-COTRAN task (Alluisi & Coates, 1967; Alluisi & Morgan, 1968), support the conclusion that the DR-COTRAN task permits the measurement of the same nonverbal-mediational aspects of intellectual functioning as provided for in the third, or problem-solving, phase of the 3P-COTRAN task. The two versions of the task differ in terms of some apparently nonessential characteristics, and in these cases the differences favor the DR-COTRAN version for use as an additional task in the multiple-task performance (MTP) battery.

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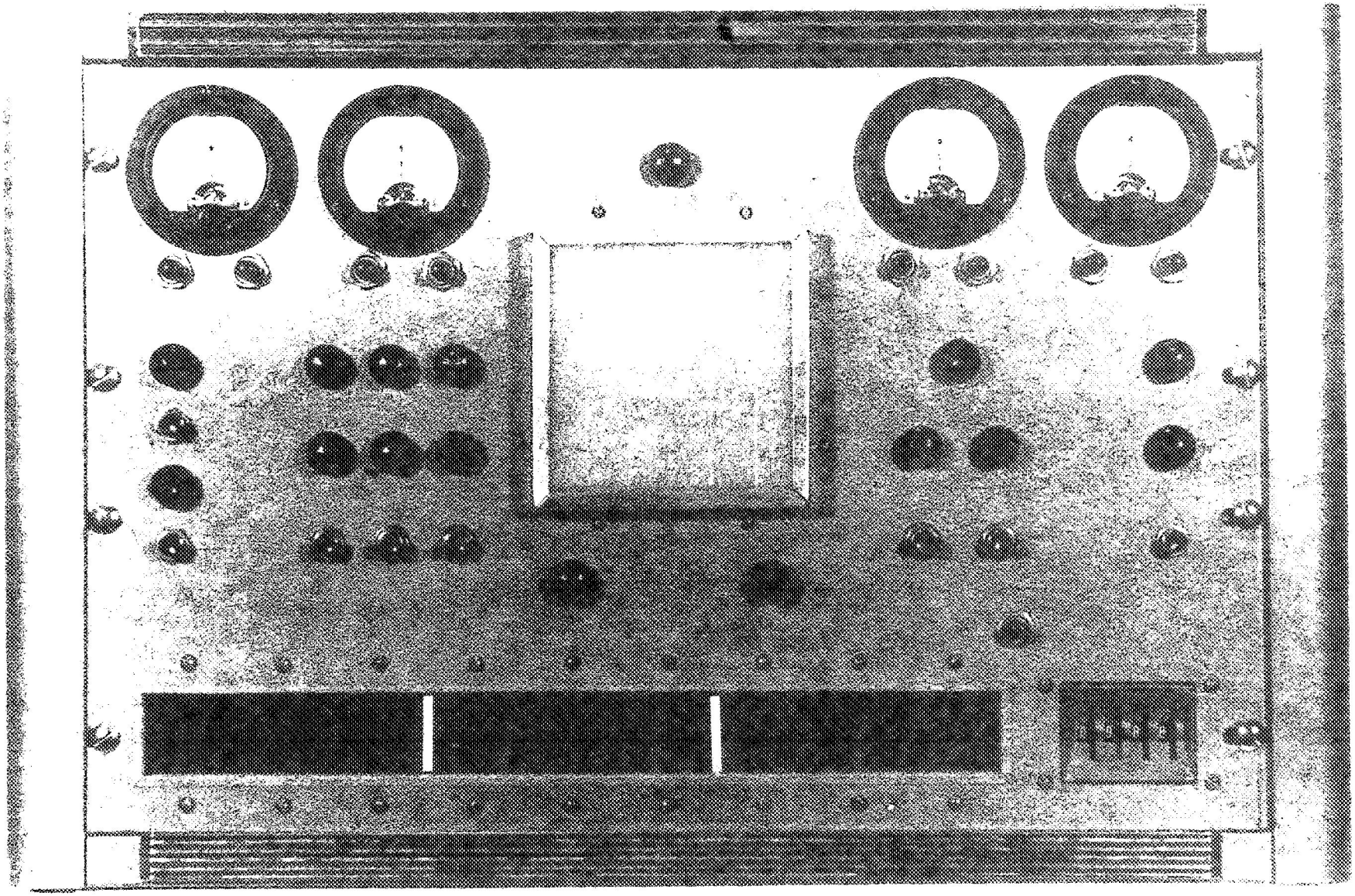
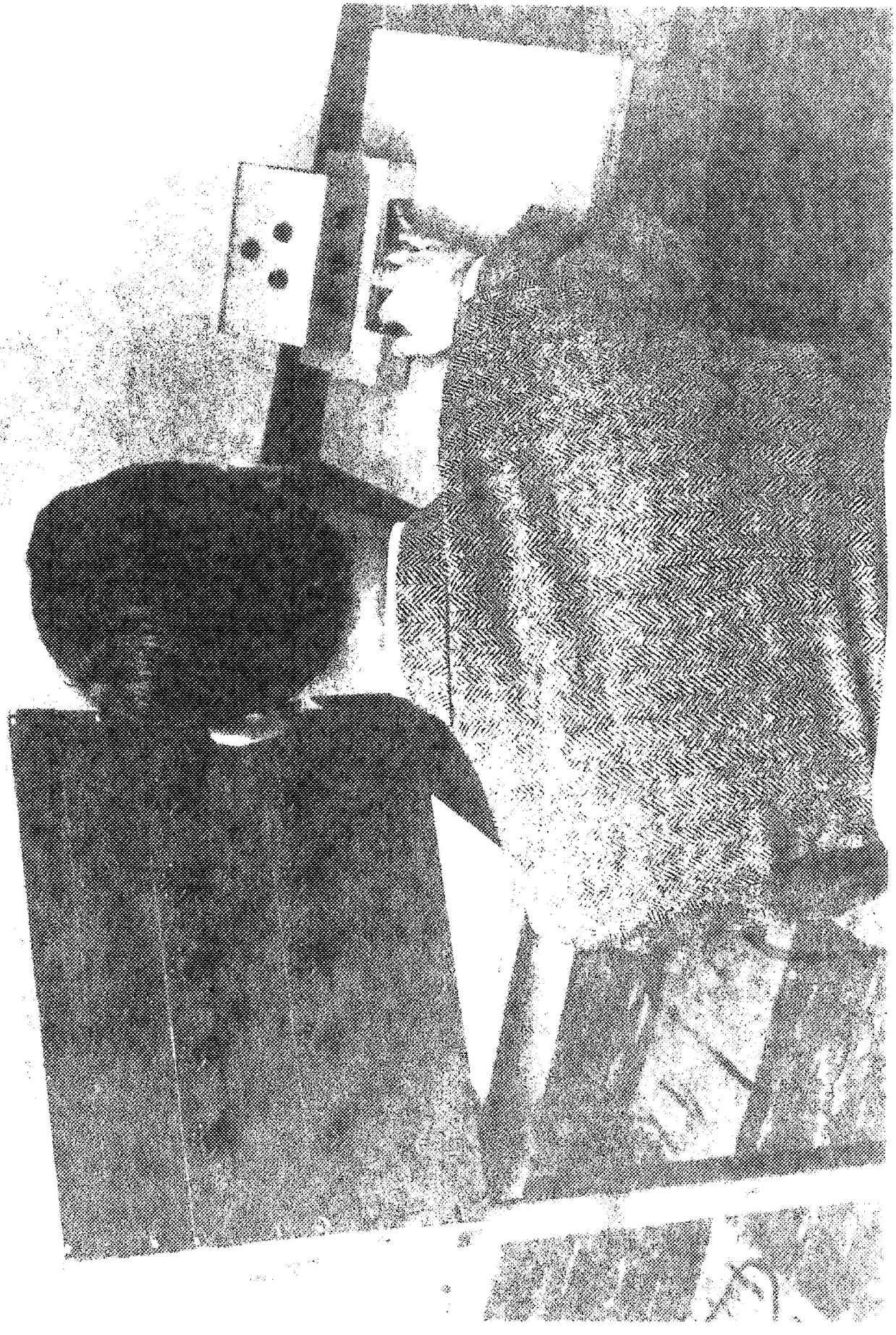
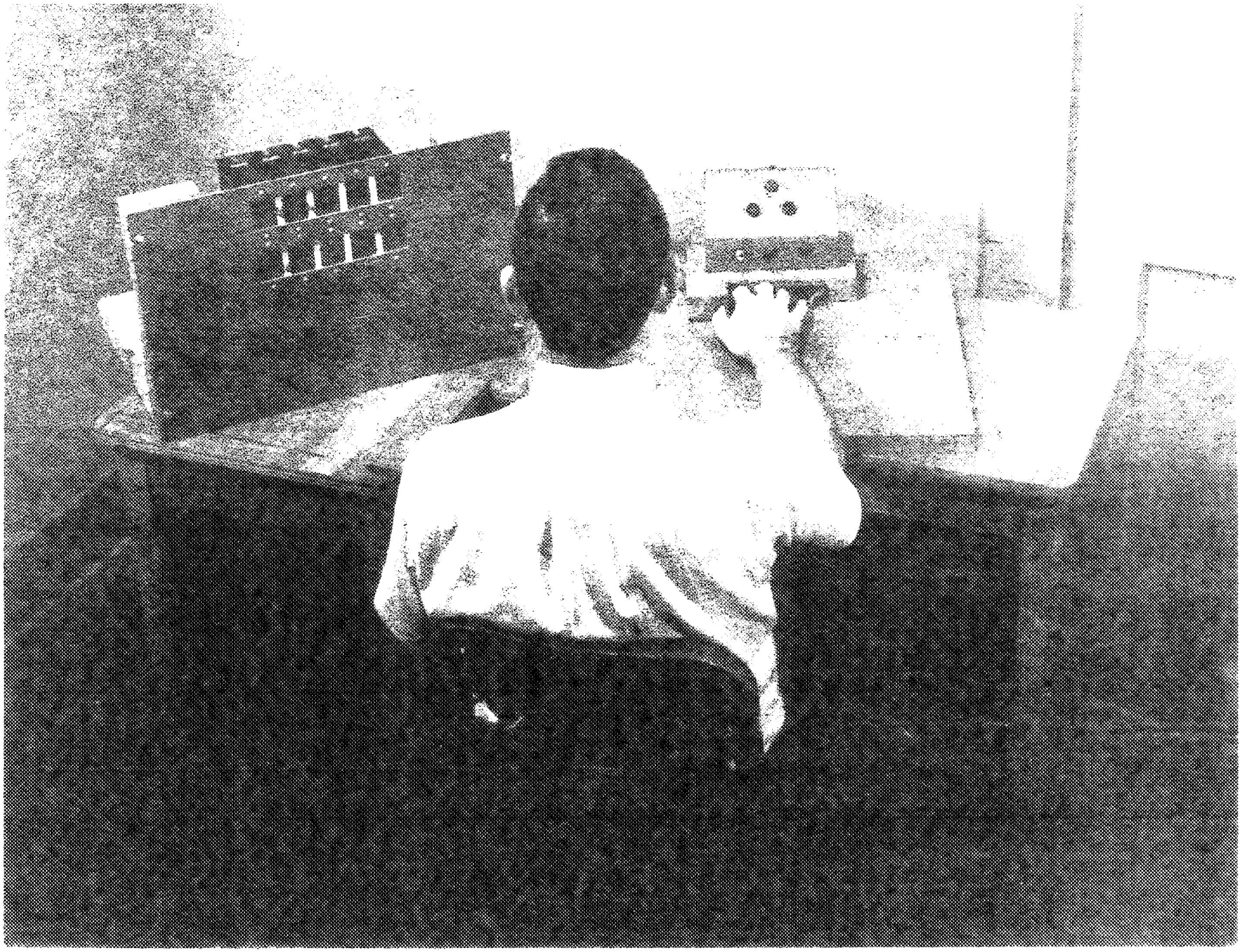






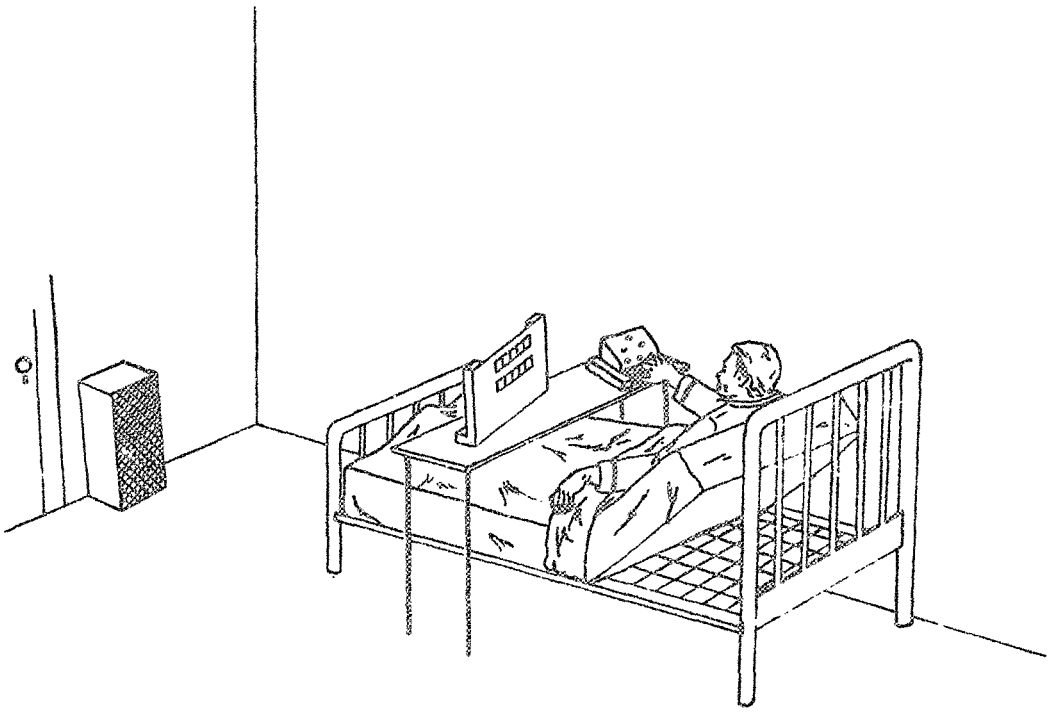


Figure 4.--Schematic representation of subject in the semi-seated bed position occupied during 3P-COTRAN and DR-COTRAN (shown) testing in Experiment II.

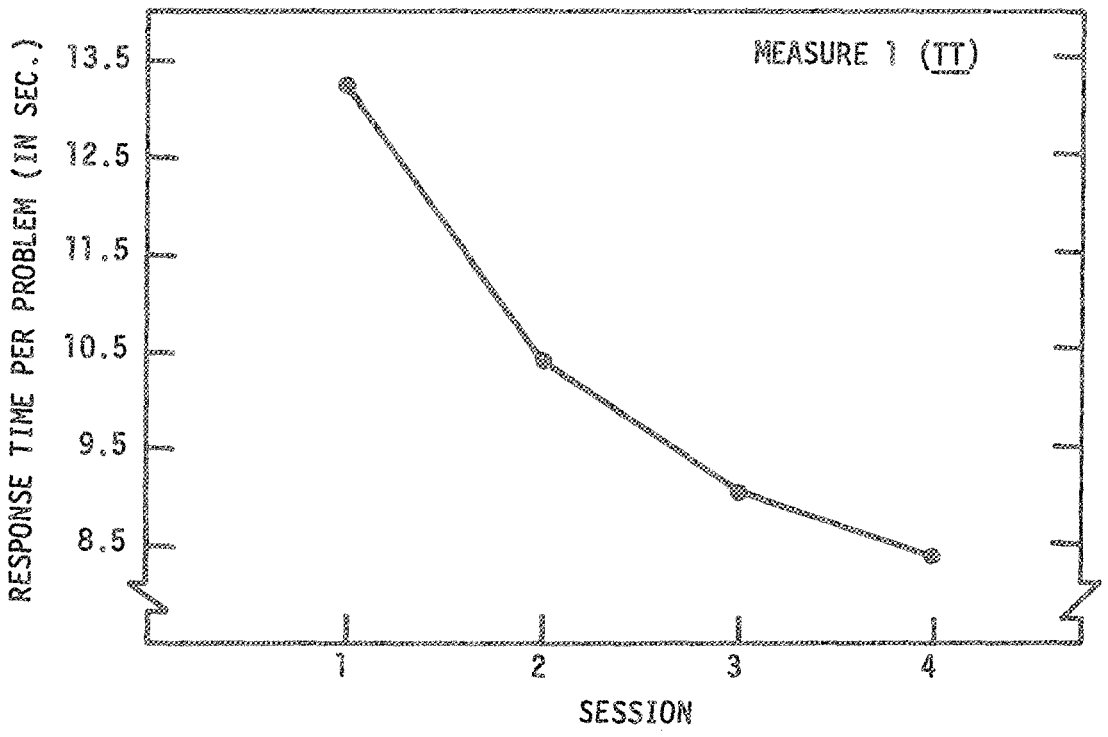


Figure 5.--Mean total response time (TT, measure number 1) as a function of practice over four sessions of 27 DR-COTRAN problems each. This measure represents factors I and II, the general and speed factors.

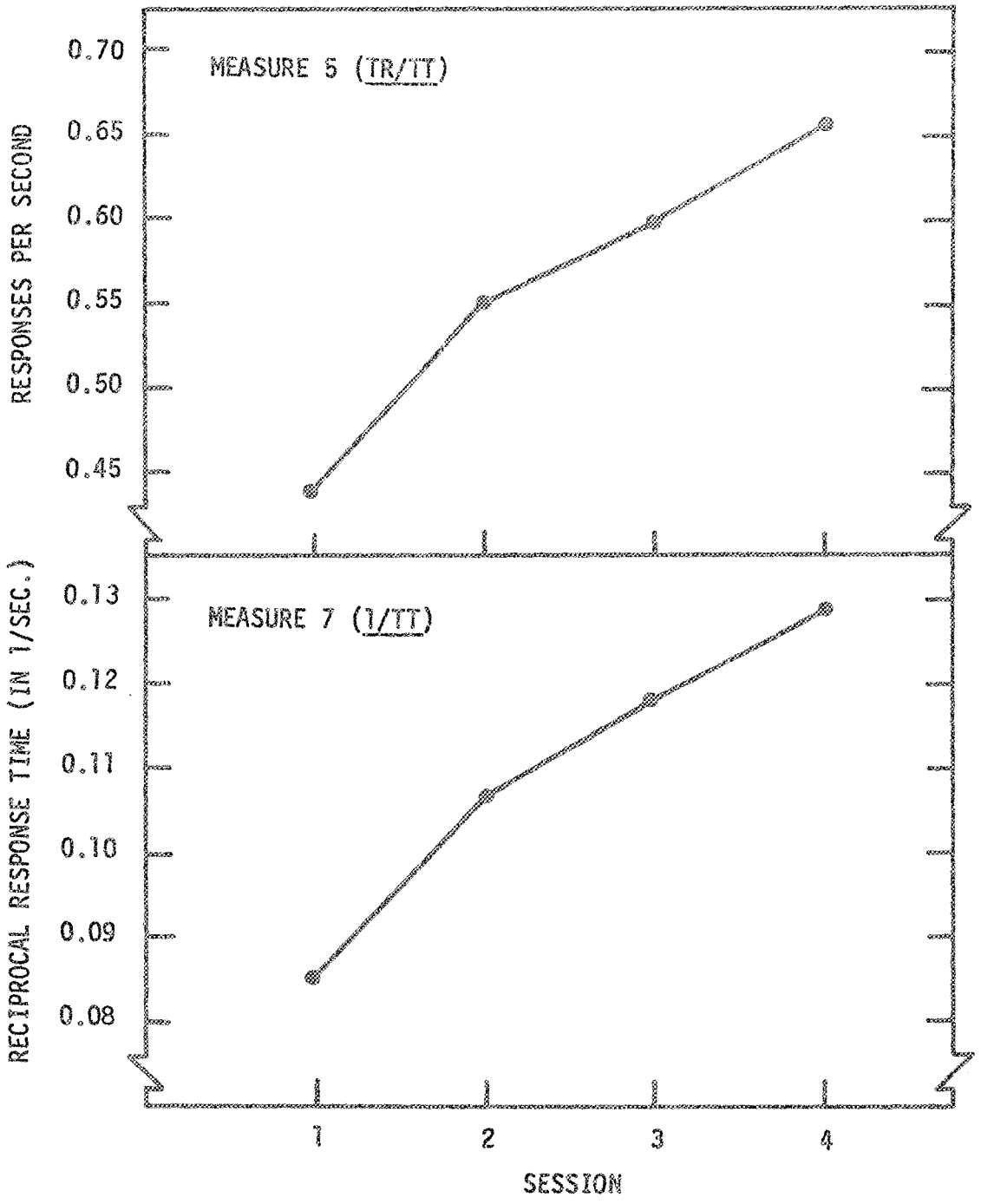


Figure 6.--Mean ratio of total responses to total response time (TR/TT, measure number 5) and mean reciprocal of total response time (1/TT, measure number 7) as functions of practice over four sessions of 27 DR-COTRAN problems each. These measures represent factor II, speed in problem solving.

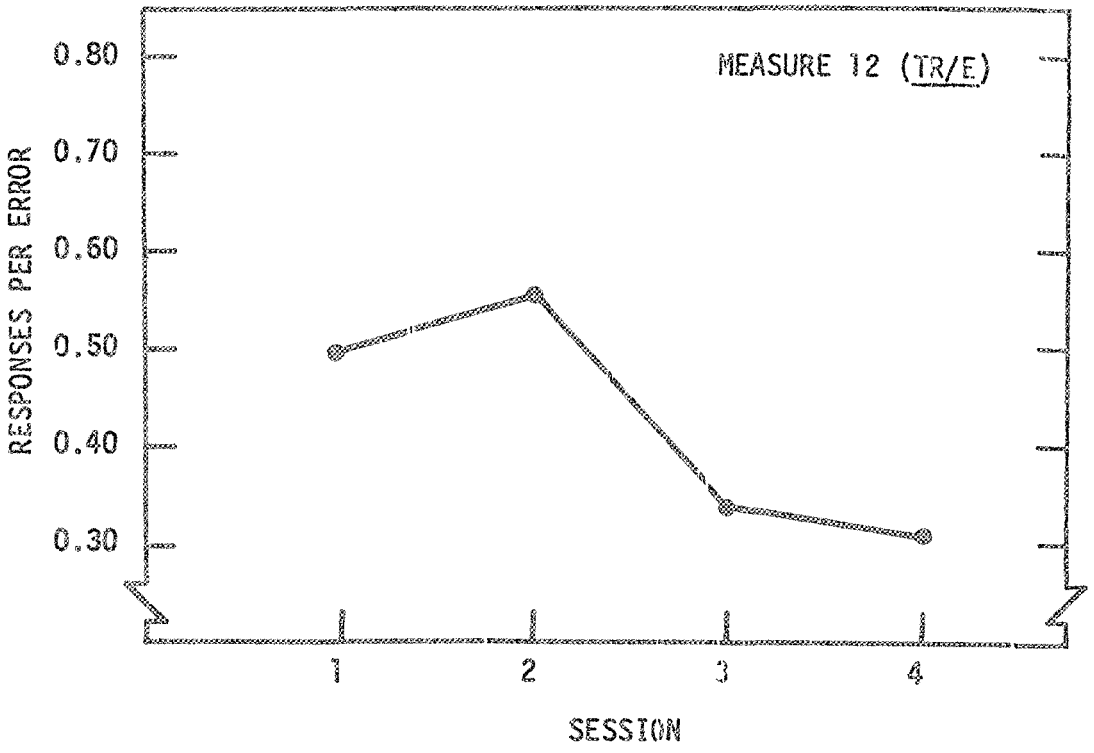


Figure 7.--Mean ratio of total responses to total errors (TR/E, measure number 12) as a function of practice over four sessions of 27 DR-CCTRAN problems each. This measure represents factor III, accuracy in problem solving.

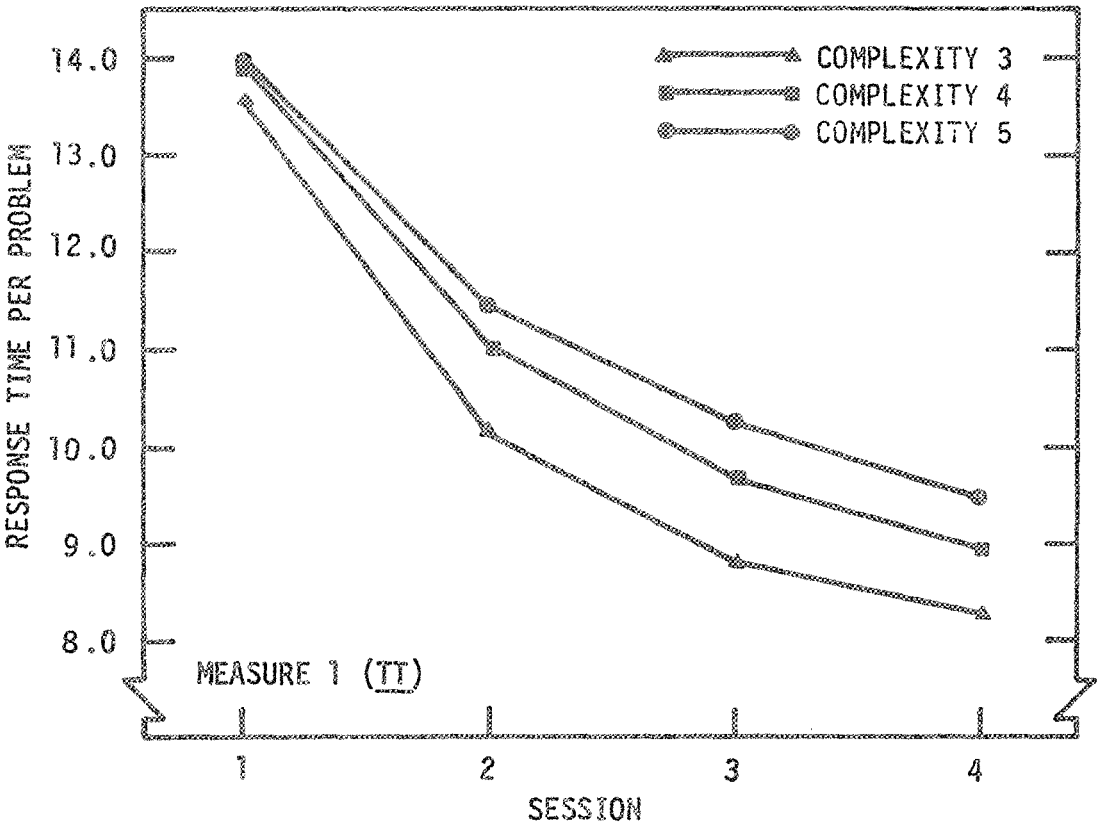


Figure 8.--Mean ratio of total responses to total response time (TR/TT, measure number 5) and mean reciprocal of total response time (1/TT, measure number 7) at three levels of transformation complexity as functions of practice over four sessions of nine DR-COTRAN problems of each complexity. These measures represent factor II, speed in problem solving.

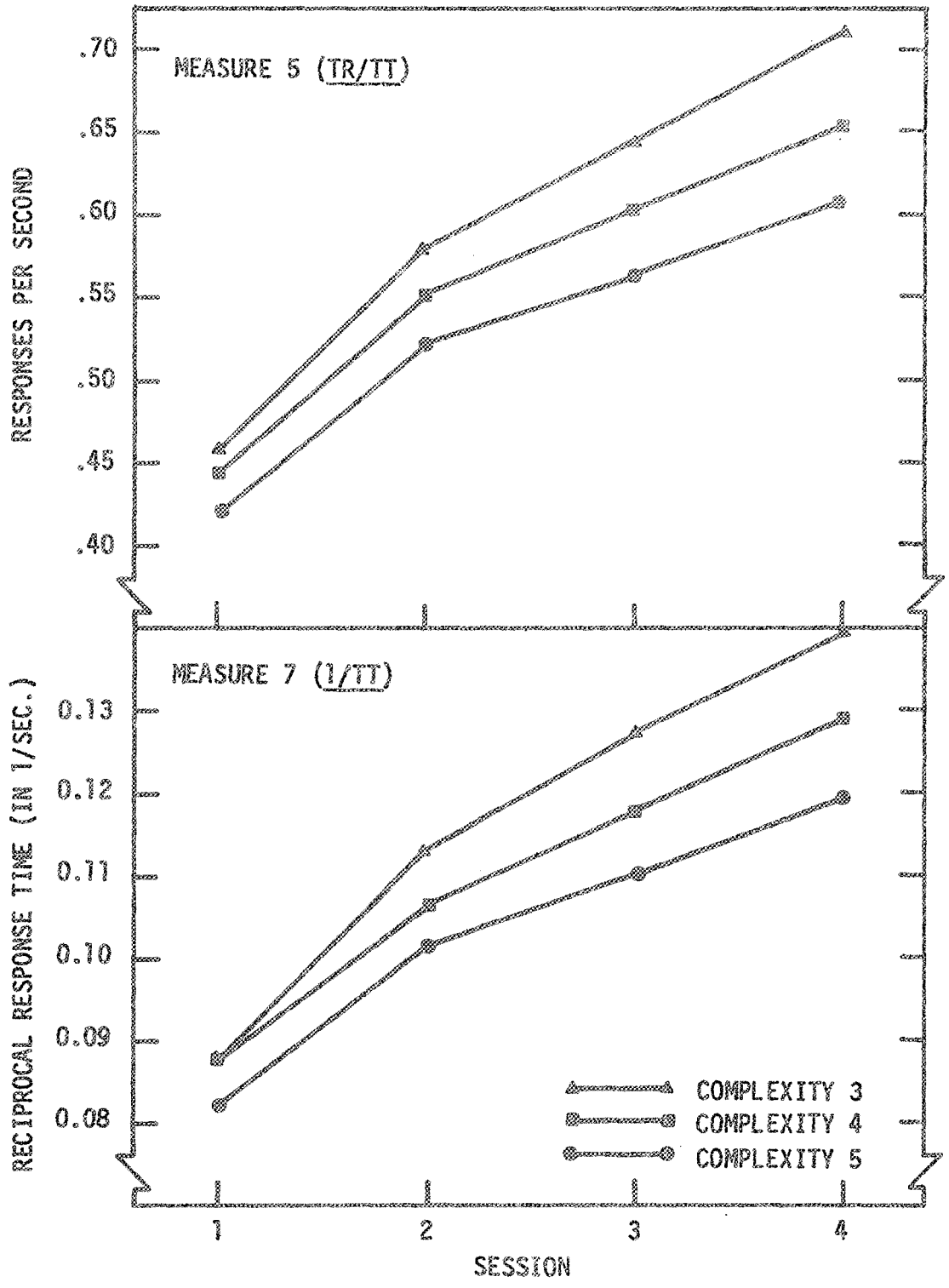


Figure 9.--Mean total response time (TT, measure number 1) for problems at three levels of transformation complexity as a function of practice over four sessions of nine DR-COTRAN problems of each complexity. This measure represents factors I and II, the general and speed factors.

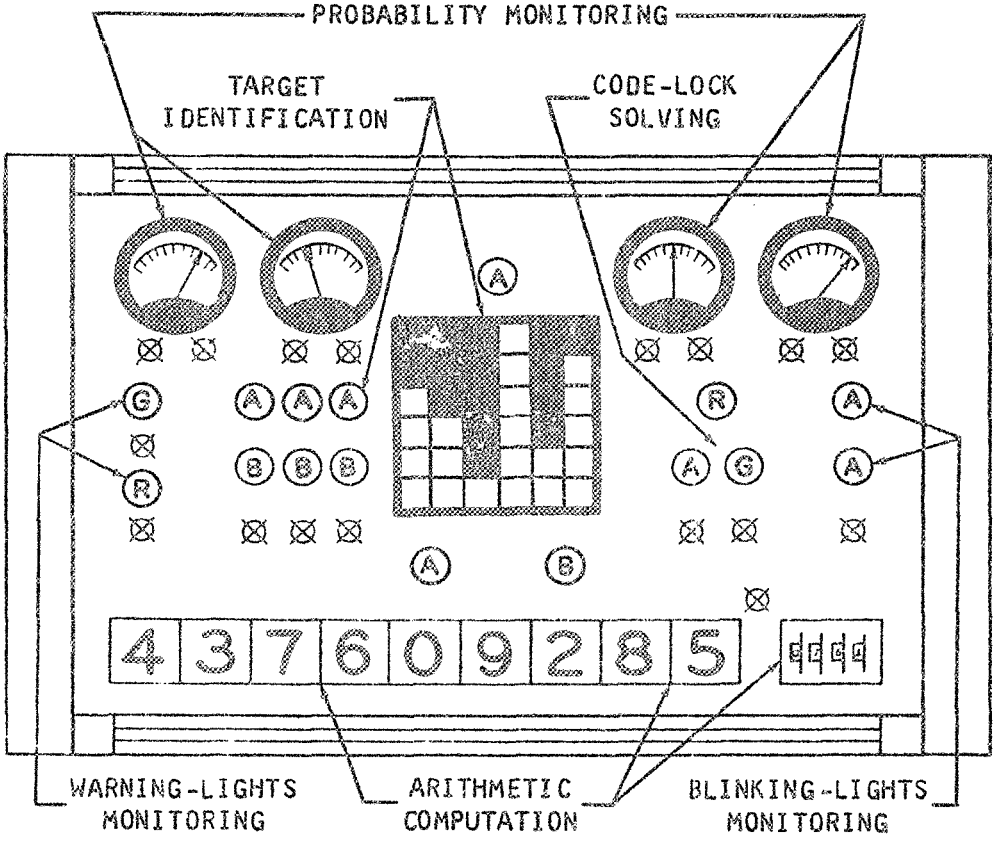
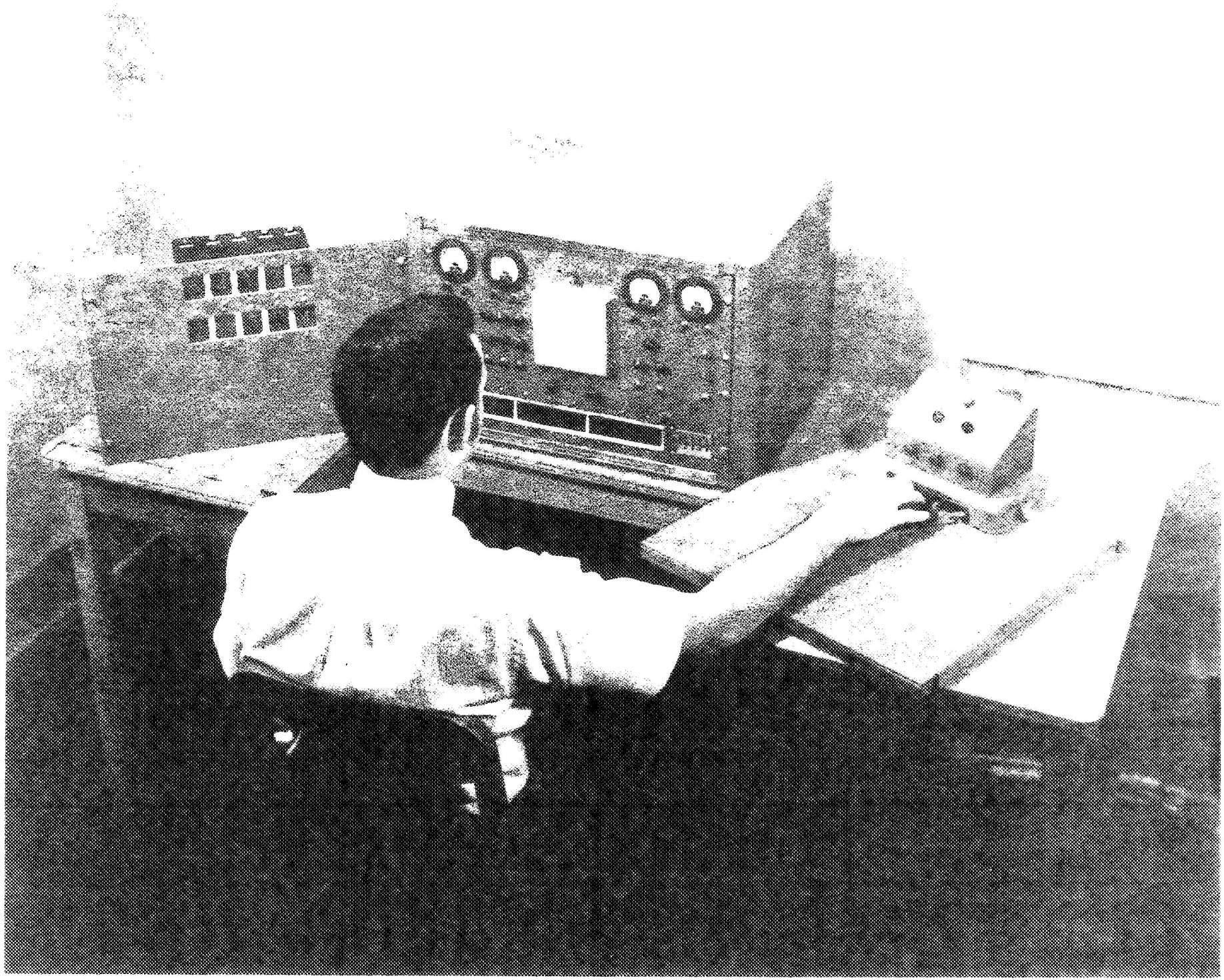


Figure 10.--Schematic diagram of the front view of an MTP operator, panel. Letters in circles represent indicator lights, A--Amber, B--Blue, G--Green, and R--Red; the smaller circles with crossing diagonals represent push-buttons.



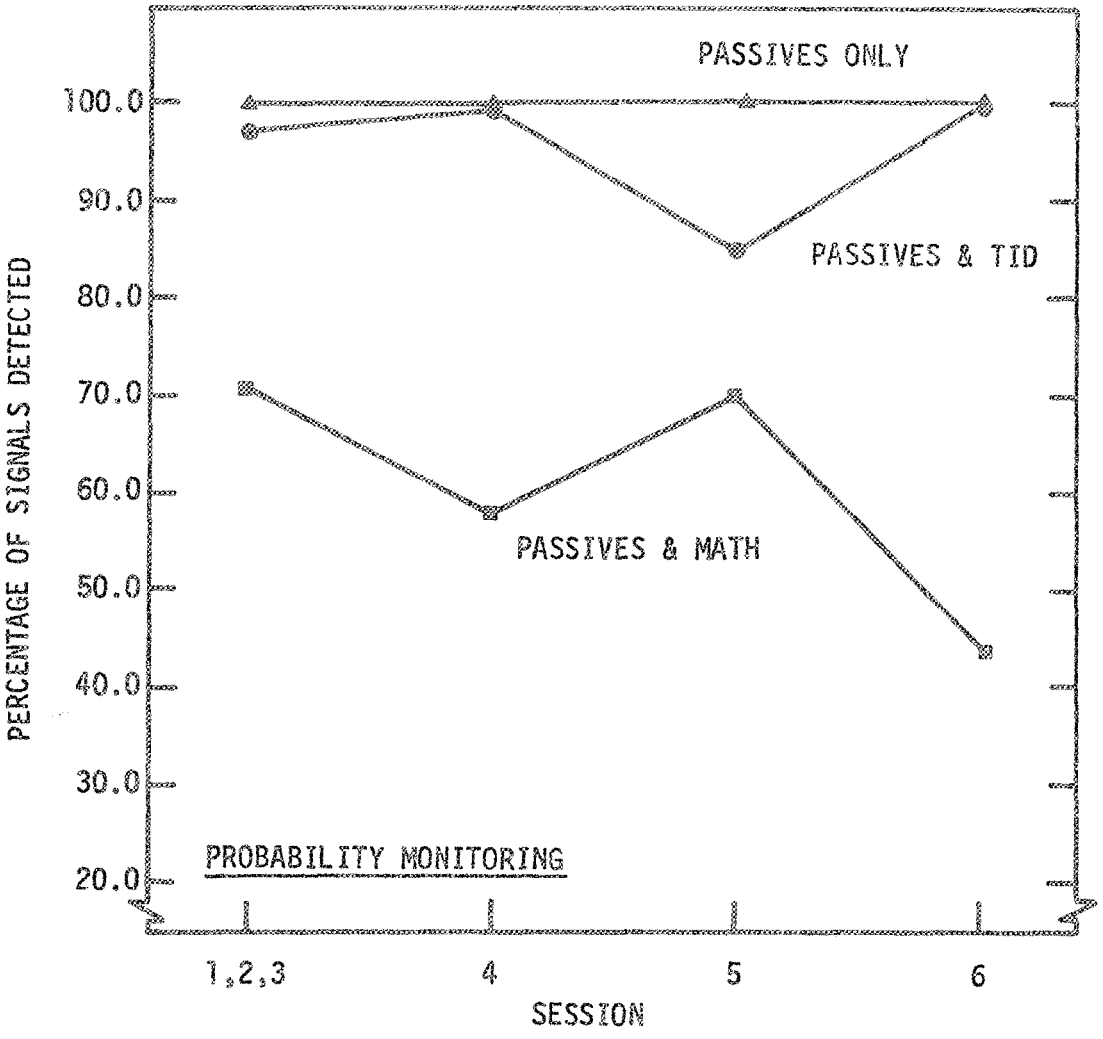


Figure 12.--Mean percentage of probability monitoring signals correctly detected under three work-load conditions over six 30-minute sessions. The average of sessions 1-3 (first point) represents performance with MTP-battery tasks only; 27 DR-COTRAN problems were concurrently solved during each of the remaining three sessions (4, 5, and 6).

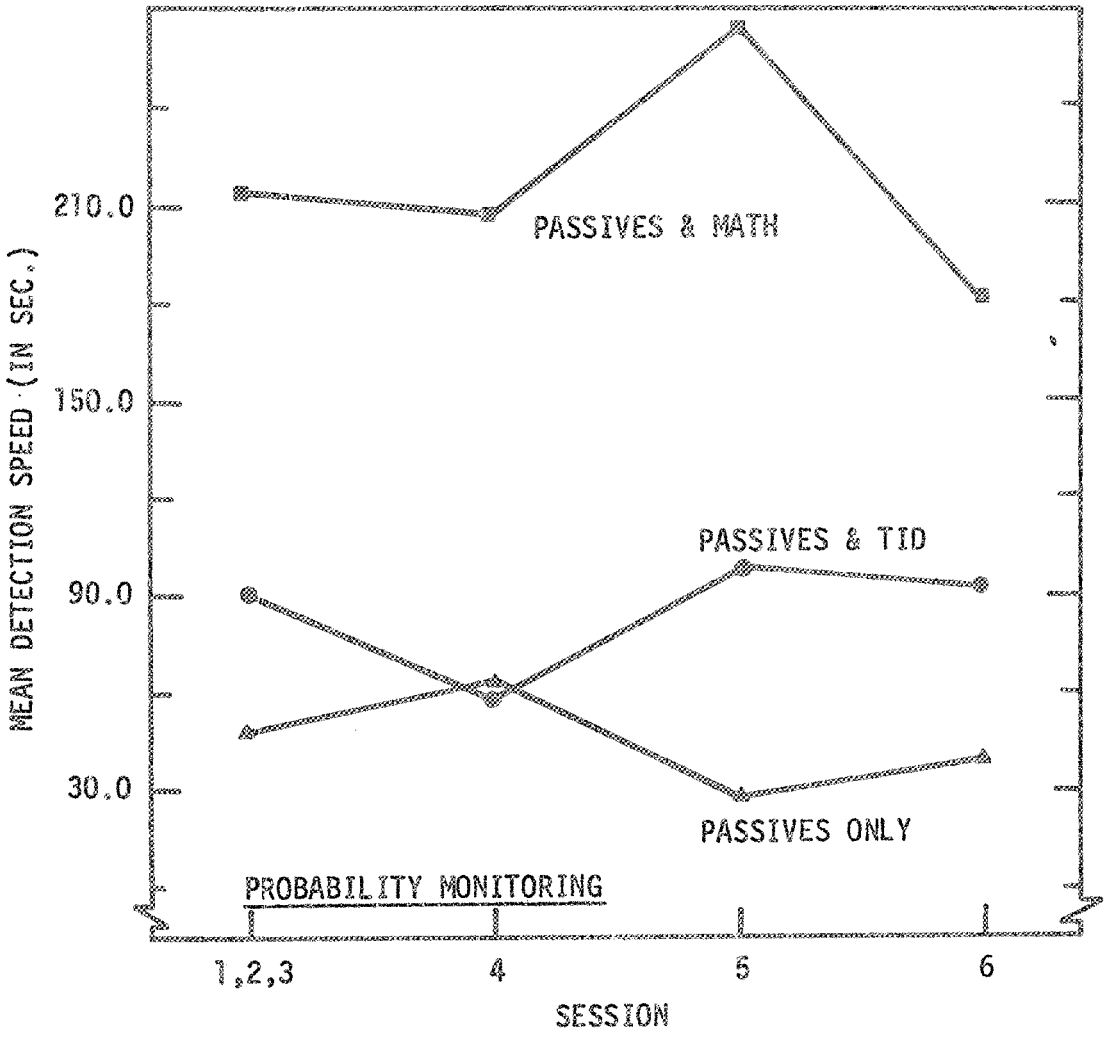


Figure 13.--Mean speed in correctly detecting probability-monitoring signals under three work-load conditions over six 30-minute sessions. The average of sessions 1-3 (first point) represents performance with MTP-battery tasks only; 27 DR-COTRAN problems were concurrently solved during each of the remaining three sessions (4, 5, and 6).

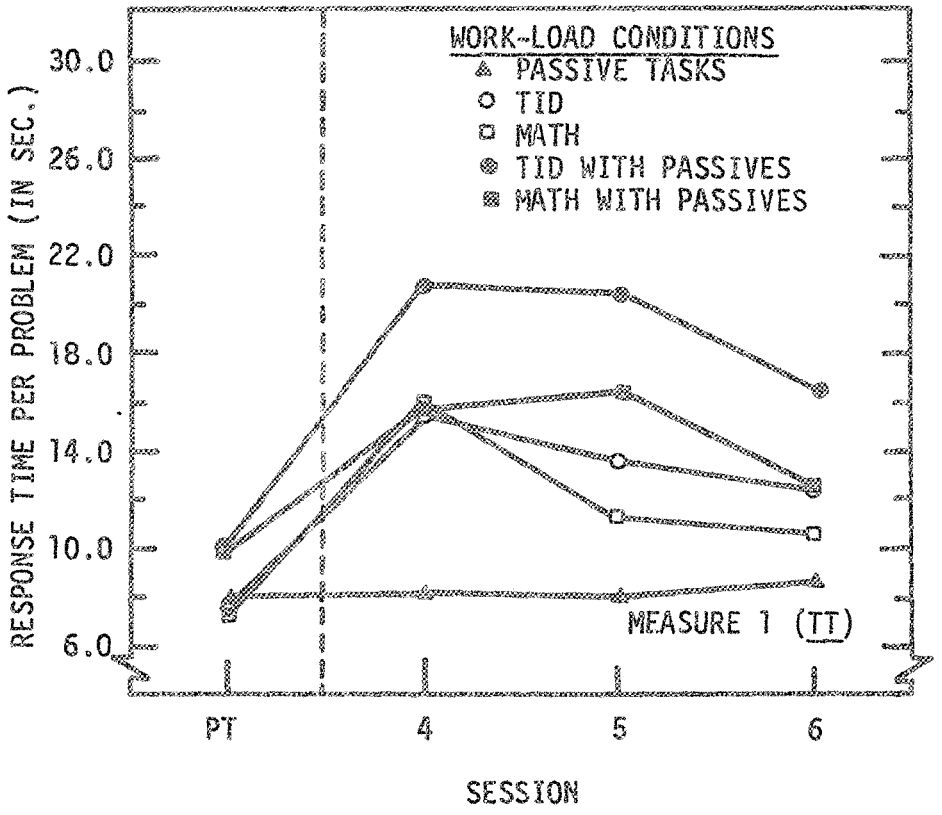


Figure 14.--Mean total response time (TT, measure number 1) for DR-COTRAN problems time-shared during sessions 4, 5, and 6 at five different work-load conditions--i.e., with five different combinations of tasks from the MTP battery.

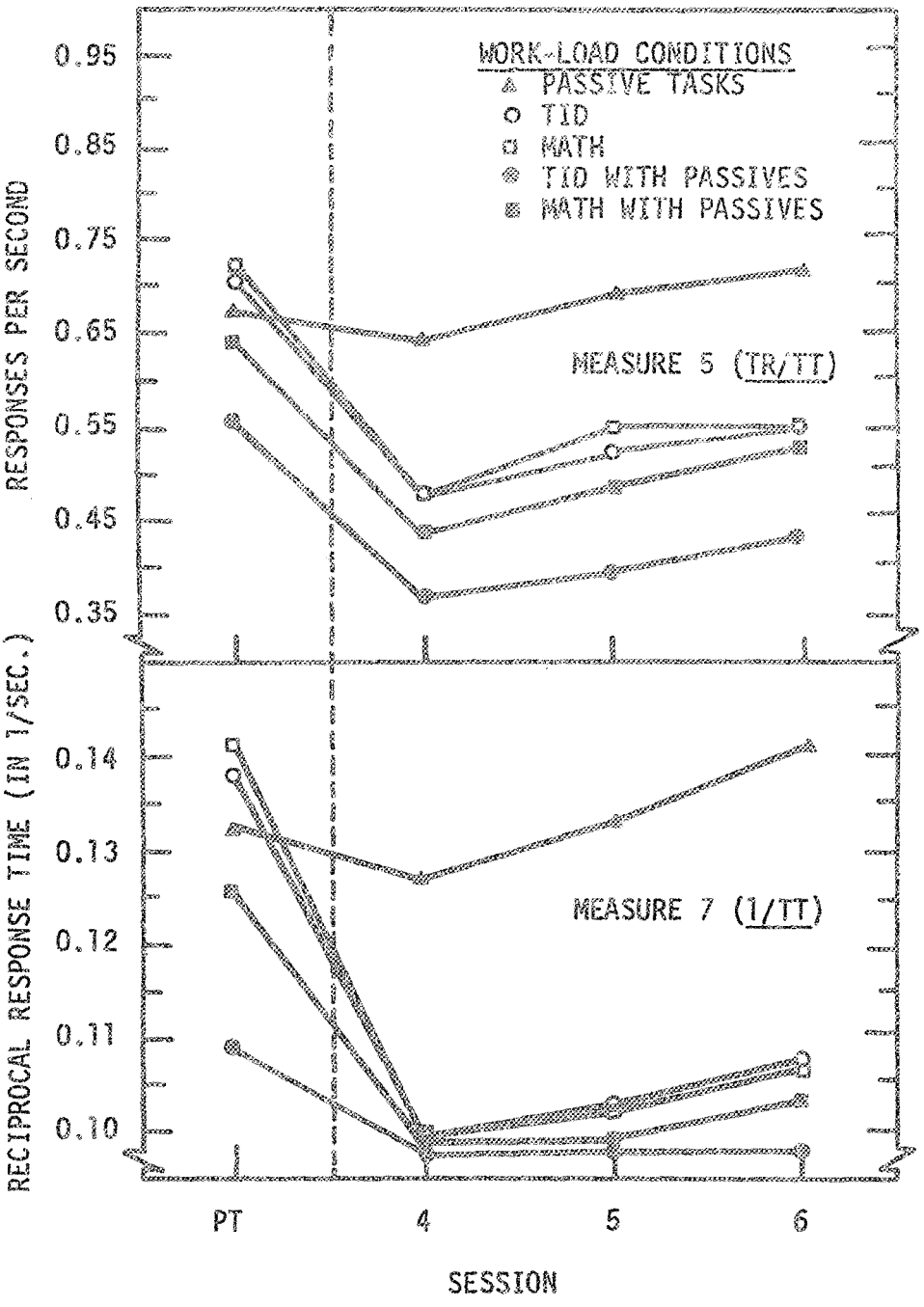


Figure 15.--Mean ratio of total response to total response time (TR/TT, measure number 5) and mean reciprocal of total response time (1/TT, measure number 7) for DR-COPAN problems time-shared during sessions 4, 5, and 6 at five different work-load conditions--i.e., with five different combinations of tasks from the MDF battery.